SECTION 7

HYDRAULIC DISCHARGE MEASUREMENTS ON THE INTERNATIONAL SECTION OF THE ST. LAWRENCE RIVER

7.1 Ogdensburg Section, 1867-1868.

7.1.1 Purpose.

The first measurements of flow in the St. Lawrence River were made by D. Farrand Henry of the U.S. Lake Survey District, Corps of Engineers, in 1867. Henry again measured the flow in 1868, after revising his method of measuring discharge. Both of these series of measurements were part of a larger project to measure the flow in the Great Lakes connecting channels. Measurements were also made in the St. Marys River (1867), the St. Clair River (1867 and 1868) and the Niagara River (1867 and 1868). These measurements are described in Sections 3, 4 and 6. The measurements made in 1868 were recomputed by the U.S. Lake Survey District in 1947, using newer technology gained in the 1900s.

7.1.2 Description of Section.

In 1867, discharge measurements were made in the St. Lawrence River about one mile above Ogdensburg, New York. Two section lines were established, approximately 700 feet apart. The section lines were divided into 18 divisions or panels, about 200 feet apart. Discharge measurements using floats were made from August 3 through September 17, 1867.

In 1868, discharge measurements were again made at this location. This time, however, only one section line was used; it was divided into 23 panels. A series of 53 discharge measurements were made between June 15 and September 14, 1868.

A map showing the location of this section was not recovered. However, the location of Ogdensburg, New York, is shown on Figure 7-1.

7.1.3. Measurement Techniques.

In 1867, the determination of the St. Lawrence River discharge was made by means of double floats. Subsection 3.1.3 (St. Marys River, 1867) details the method used to make these measurements. In summary, two section lines were established and sounded, and the movement of floats past these sections were observed. The floats were set in the river with the lower part at various depths. The point where each float crossed the upper and lower sections, together with the time required for passage, were recorded. Velocities were observed at each five feet of depth.

Henry believed that the floats gave velocities as much as ten percent too large. During the summer of 1868, Henry made flow observations using electric recording current meters that he devised from old anemometers. A description of these meters can be found in the Report of the Chief of Engineers, 1869, page 565.

Henry's meter would be lowered into the water and a set of cups, attached to an axis, would spin as the water passed. An electric devise would record the number of revolutions of the cups, as they completed an electric circuit on each full revolution. The meters were rated often (before, during and after the measurement series) to determine a conversion from revolutions per unit of time to feet per second.

Velocity measurements, for the purpose of determining discharge through the section, were made at points 200 feet apart across the section. To determine the vertical distribution of the velocity, measurements were made at each five feet of depth. Only a few positions were occupied a day. Several attempts were made to measure the entire section in one day. This was done by only measuring at two of three depths at each station. No record of water surface elevations was kept, except those at the section.

7.1.4 Discharge Computation.

1867 Reduction of 1867 Measurements. The soundings of the two cross-sections were averaged to obtain a mean cross-section. This mean cross-section was divided into 11 parts or panels, and an area was computed for each.

The actual distance each float traveled in passing between the two section lines, as determined from the angles from the base line recorded by the observers, divided by the time required for passage gave the velocity of the river at that depth and position, within the mean section. The daily panel discharge was determined by multiplying the panel area, corrected for stage, by the mean velocity of all the floats that passed through the panel during the day. These daily panel discharges were tabulated and their mean gave the panel discharge for the period. The discharge of the river for the period was obtained by adding together the panel discharges. This value, as determined by Henry, gave the discharge of the river as 321,143 cfs for the period August 3 through September 14, 1867.

1868 Reduction of 1868 Measurements. Velocity curves were constructed by plotting all the velocities measured at each five-feet of depth, at each measuring station. From these curves, the velocity measured at each five-feet of depth of a panel was reduced to a mean velocity for the panel for a particular measurement. The mean velocity measured in a panel for a particular measurement was multiplied by the panel area, derived from soundings and water level readings, to obtain the discharge through the panel.

The discharge through the entire section was computed by finding the ratio between the mean discharge of each panel for all measurements and that of the whole river and then multiplying the discharge found in any panel by this ratio. Discharges computed from the side panels were usually considered inaccurate, due to weeds and dead water.

1947 Reduction of 1868 Measurements. Using the observed velocities at five-feet depths and soundings from the 1868 measurements, a profile of each river section was drawn and divided into panels. Panel areas were determined; these areas represented the average condition during the period of observations. Velocities observed in each panel were tabulated. Means of each five-feet depth were taken and reduced to 0.4 depth velocities, according to the vertical velocity curve, as determined on the St. Clair River in 1944. The 0.4 depth velocities were plotted and a transverse velocity curve was drawn. From this curve, velocities for mid-panel at the 0.4 depth were determined. These mid-panel 0.4 depth velocities were reduced to mean panel velocities using coefficients derived from the vertical and transverse velocity curves. The product of the mean panel velocity and panel area gave the average panel discharge during the period of observations. The sum of the panel discharges gave an average total river discharge for the period of 270,000 cfs, as compared to an average of 272,100 cfs computed by Henry in 1868.

Henry's report on the measurements made in 1867 is given in the Report of Chief of Engineers, 1868, page 949. The report on the 1868 measurements is in the Report of Chief of Engineers, 1869, page 563. The 1947 reduction of the 1868 measurements is documented in file 3-3100 of the U.S. Lake Survey District Archives (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland). Tables 7.1 and 7.2 (see Appendix C) summarize the discharge measurements made in 1867 and 1868, respectively.

7.2 Ogdensburg Section, 1898.

In 1898, C.B. Stuart measured the flow at a section he established near Ogdensburg, New York, for the Deep Waterways Commission. No other information was recovered.

7.3 Three Points Section, 1900-1913.

7.3.1 Purpose.

Prior to construction for the St. Lawrence Seaway, a series of rapids existed in the river at Iroquois, Ontario, called the Galop Rapids. They have since been flooded by the St. Lawrence power and navigation project, in late 1958. The St. Lawrence River from Lake Ontario to the Galop Rapids was considered an arm of Lake Ontario. From the Lake Ontario to the Galop Rapids, a distance of nearly 65 miles, the river fell approximately one foot. At the Galop Rapids, the river fell some 16 feet in approximately 1-1/2 miles. Twelve miles further downstream was another rapids, the Rapide Plat. These two rapids were natural weirs, by which the flow of the St. Lawrence River was determined. Measurements of flow in the St. Lawrence River were made several times between 1900 and 1913, at the hydraulic section known as Three Points, located between these rapids. These measurements were used to calibrate stage-discharge equations for Lake Ontario outflow.

7.3.2 Description of Section.

The Three Points Section was established by the U.S. Lake Survey District in 1900, perpendicular to the direction of flow. It spanned the river just below Iroquois, Ontario, approximately 1,500 feet above Pinetree Point and the confluence of Parlow Creek; about 15 miles downstream from Ogdensburg, New York. The section, which was 1933 feet wide, was divided into 17 panels.

The first discharge measurements were made, at the section, in September 1900. Between September 26 and December 7, 1900, 40 measurements were made. Additional measurements were made between April 29 and July 3, 1901. The section was again recovered in 1908, and 26 discharge measurements were made between September 21 and October 2. Thirty-two measurements were made in June 1911 and 30 were made in October 1911. In October 1913, an additional series of 35 measurements were made.

The approximate location of this discharge measurement section is shown on Figure 7-1.

7.3.3 Measurement Techniques.

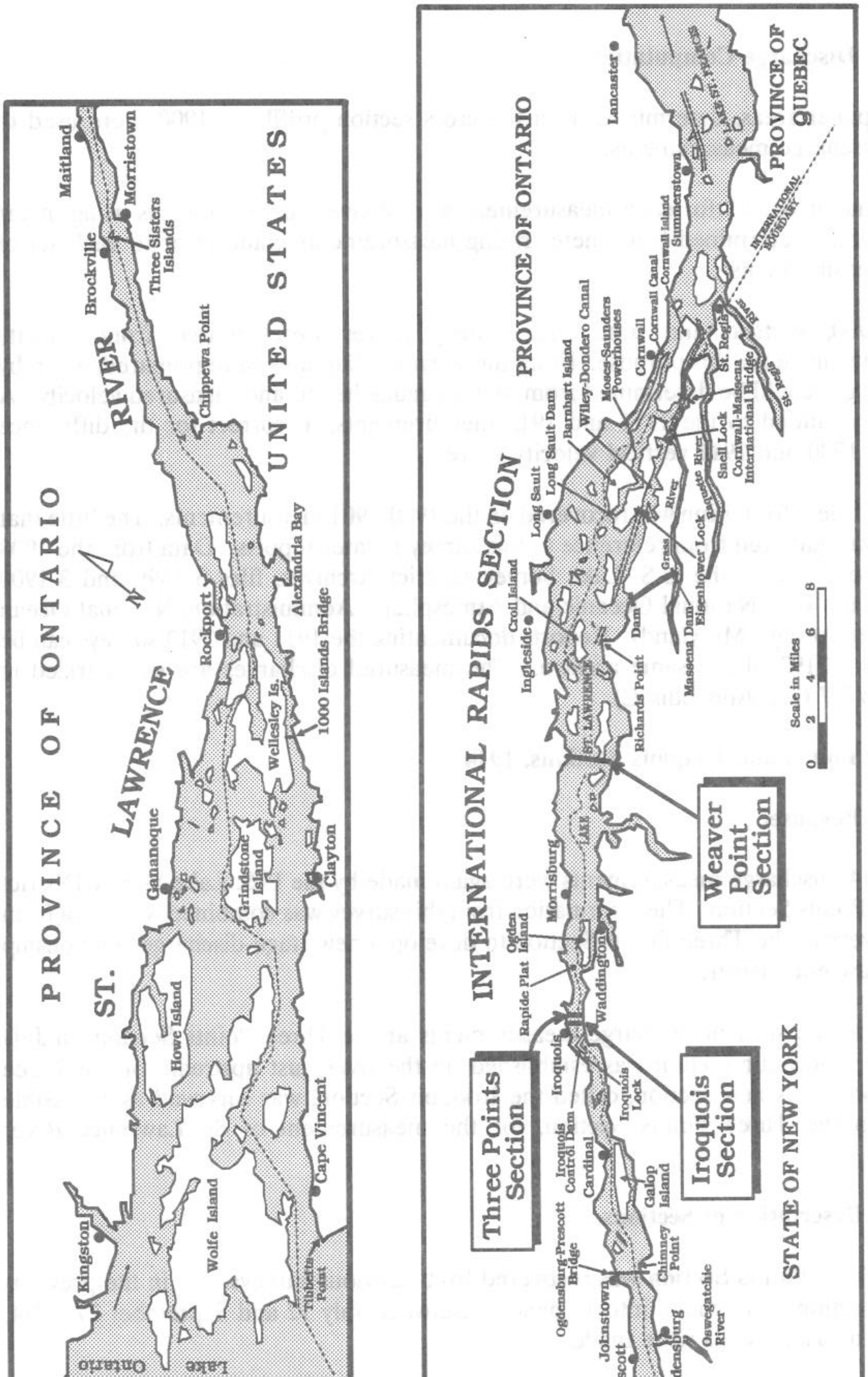
The section was sounded in 1900 and a cross section profile was determined. From this profile, the areas of the 17 panels were computed. The section was re-sounded, in 1911.

The water level at the section was recorded by a temporary gauge installed on a small timber crib at the south end of the section line. Levels were also recorded at Ogdensburg, New York, and at gauges on the navigation locks above the section.

To measure the velocities in the panels, four B-type Haskell current meters were used. A small Price meter was used to determine velocities in the shallow ends of the section.

Vertical velocity measurements were made in 1900 and again at selected panels, in 1911. To determine the vertical velocity curve/coefficient at each panel, velocity measurements were made near the bottom and the surface, and at each tenth of the depth.

All of the discharge measurements consisted of two two-minute velocity observations at the 0.4 depth on each station, using two meters lowered simultaneously.



International Section of the St. Lawrence River
Approximate Section Locations

Figure 7-1

7.3.4 Discharge Computation.

The panel areas, determined from the cross section profile of 1900, were used to reduce all discharge measurements.

The meter counts for each measurement were converted to velocities using meter rating equations, determined from meter rating measurements made prior to each set of discharge measurements.

In 1900, vertical and transverse velocity curves were plotted from velocity measurements made for this purpose. From these curves diagrams were prepared, whereby panel discharges could be determined from section gauge height and measured velocity. A correction was added to the 1911 and 1913 measurements, to correct for the difference between the 1900 and 1911 vertical velocity curves.

Very little information was recovered on the 1900-1901 measurements. The little that was found, was gathered from reference to this survey in later reports. Data from the 1908 survey can be found in the U.S. Lake Survey District Archives, files 3-1899 and 3-1900 (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland). Reports documenting the 1911 and 1913 surveys can be found in file 3-2192 of the same archive. The measured discharges are summarized in Tables 7.3 to 7.7 (see Appendix C).

7.4 Three Points and Iroquois Sections, 1914.

7.4.1 Purpose.

In 1914, discharge measurements were again made by the U.S. Lake Survey District at the Three Points Section. The information from this survey was combined with data from previous surveys at the Three Points Section to develop a new stage-discharge relationship for the St. Lawrence River.

Prior to the start of discharge measurements at the Three Points Section, in July 1914, another hydraulic section was established on the river, just upstream of the Three Points Section. This new section, called the Iroquois Section, was surveyed as a possible alternative to the Three Points Section, for the measurement of St. Lawrence River discharge.

7.4.2 Description of Sections.

The **Three Points Section** was recovered from previous surveys. As in the previous surveys, the section was divided into 17 panels. Between July 12 and September 27, 1914, 41 discharge measurements were made.

The **Iroquois Section** was established approximately 1,800 feet upstream of the Three Points Section. The cross section was divided into 12 major panels, starting approximately 1,300 feet from the Canadian shore. The end areas were shallow and passed only about 4% of the total discharge. The measurement of discharge in these areas was handled separately from the discharge in the main portion of the section. Forty-two discharge measurements were completed at this section, between July 6 and October 23, 1914.

The approximate locations of these discharge measurement sections are shown on Figure 7-1.

7.4.3 Measurement Techniques.

The Three Points Section was thoroughly re-sounded and the resulting profile was compared to previously developed profiles. Sixteen velocity measurements at 11 points in the vertical were made at Panel 9, to redetermine the vertical velocity curve. The direction of current past the section was delineated by means of a rod float survey.

To record water levels at the section, a gauge was re-installed on a small timber crib constructed on the south end of the section line.

Discharge measurements were made at the Three Points Section in the same manner as on previous surveys. Two Haskell meters were lowered simultaneously to the 0.4 depth of the panel and two two-minute velocity measurements were made. This was done at each panel and constituted one measurement of the section. The end areas were metered with a Price meter and sounding pole.

Water levels at the Iroquois Section were recorded by a gauge which was temporarily installed on a wooden crib constructed near the south end of the section. The shallow areas of the Iroquois Section were sounded with a pole. The remainder of the section was lead-line sounded from a catamaran. The direction of the current through the section was determined from the same survey that determined current direction through the Three Points Section.

Vertical velocity measurements were made at each of the 15 panel points of the Iroquois Section. Eight or more observations were taken at each of the 11 points in the vertical (top, bottom and each tenth of the depth). The transverse velocity was measured at the 0.4 depth at various points along the section.

In the shallow end areas of the Iroquois Section, discharge measurements consisted of a series of measurements made at the 0.2 and 0.8 depths, at 50 to 100-foot intervals, using a Price meter. In the rest of the section, metering stations were located near each panel midpoint. Because of shoaling about 1,000 feet upstream of Panels 12 to 14, three additional metering stations were used, located between stations 14 and 15, 15 and 16, and 16 and 17. Discharge measurements at these 15 stations were made with two Haskell velocity meter lowered to the 0.4 depth of a panel. Two two-minute velocity readings were made by both meters simultaneously, during each measurement.

7.4.4 Discharge Computation.

In all cases of velocity measurements, the revolutions recorded by the meters were converted to velocities based on the ratings of the meters.

At the Three Points Section, panel discharges were obtained from graphs prepared from the 1900-1901 survey of this section. Using the water level recorded at the section gauge at the time of the measurement and the index velocity (the average of the 2 readings made with a particular meter at the 0.4 depth) as arguments, panel discharges were read from the graph. The sum of the panel discharges plus the discharge through the end areas, plus a correction of 0.3%, equals the total discharge through the Three Points Section for a particular measurement and meter. The correction of 0.3% was derived in 1906, when an earlier computation of coefficient was revised.

At the Iroquois Section, the velocity and directional coefficients were determined from measurements made for the purpose of determining coefficients. The vertical coefficient related the panel index velocity to the velocity distribution in the vertical. The transverse coefficient related the index velocity to the horizontal distribution of velocity. The directional coefficient gave the component of the index velocity normal to the section.

For each discharge measurement at the Iroquois Section, the average velocity measured at the 0.4 depth of a panel by a particular meter was multiplied by the three coefficients for the panel. This adjusted velocity was then multiplied by the panel area, adjusted for the water level at the section, to determine the panel discharge for that measurement.

The report documenting the discharge measurements at both sections can be found in the U.S. Lake Survey District Archives, file 3-2192 (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland). The measured discharges are listed in Tables 7.8 and 7.9 (see Appendix C).

7.5 Measurements by Canadian Department of Public Works and Department of Railways and Canals: Three Points Section, 1915-1920; Brockville Section, 1920; Iroquois Point Section, 1923-1925; Leishmans Point Section, 1935.

Discharge measurements were made in the St. Lawrence River by the Canadian Department of Public Works at the Three Points Section in 1915 (July 28 - December 11; 60 measurements); in 1916 (June 30 - December 15; 59 measurements); in 1917 (May 21 - November 26; 100 measurements); in 1918 (July 9 - December 13; 51 measurements); in 1919 (June 16 - November 24; 70 measurements) and in 1920 (April 30 - November 13; 46 measurements). Measurements were also made by the Canadian Department of Railways and Canals at the Brockville Section in 1920 (January 30 - May 27; 25 measurements); at the Iroquois Point Section in 1923 (September 11 - November 2; 12 measurements); in 1924 (June 10 - August 22; 4 measurements) and in 1925 (November 11 & 12; 3 measurements) and at the Leishmans Point Section in 1935 (September 16 - October 16; 11 measurements). Lacking any evidence to the contrary, it is assumed that the Iroquois Section measured in 1914 is synonymous with the Iroquois Point Section (1923) mentioned above.

The approximate locations of the Three Points Section and the Iroquois Point Section (the Iroquois Section), are provided in Figure 7-1. The location of the Leishmans Point Section is shown on Figure 7-2. A map showing the location of the Brockville Section was not recovered; however, for information purposes, the location of Brockville, Ontario, is shown on Figure 7-1.

During the measurement sequences, water levels were monitored at Lock 25 and at a section gauge. The gauge at Lock 25 was referenced to the permanent bench mark "Lock 25" at elevation 236.811 feet on 1903 Datum (236.211 on IGLD 1955). The section gauge was referenced to permanent bench mark #12 at elevation 253.297 feet on 1903 Datum.

What little is known about these discharge measurements was found in the U.S. Lake Survey District Archives, file 3-3402 (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland). Tables 7.10 to 7.17 (see Appendix C) summarize these measurements.

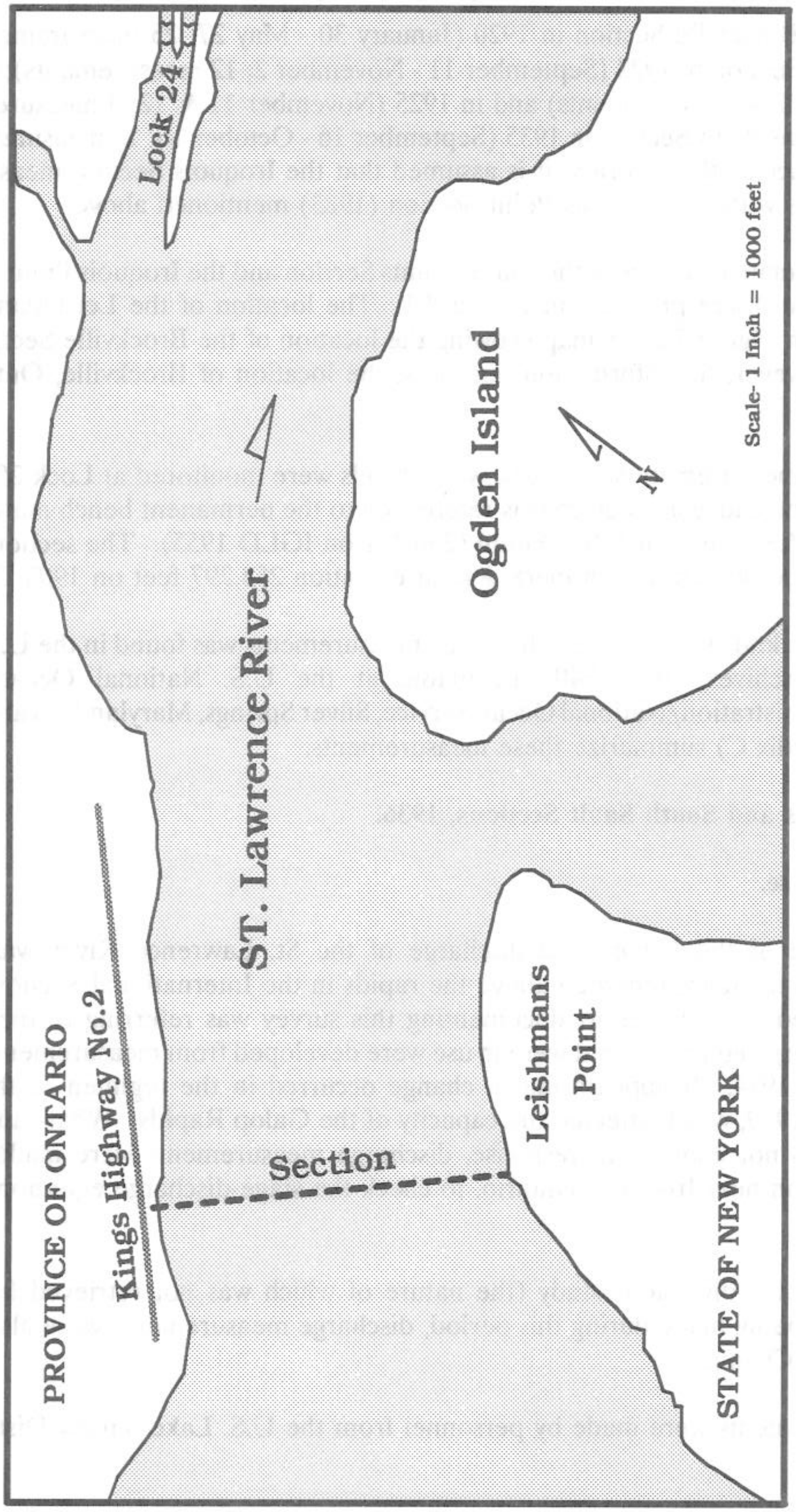
7.6 Three Points and South Sault Sections, 1936.

7.6.1 Purpose.

At the time of this survey, the discharge of the St. Lawrence River was being calculated in terms of stages recorded above the rapids in the International Section of the river. It is assumed that the report documenting this survey was referring to the Galop Rapids. The discharge equations that were in use were developed from measurements made in 1911, 1913 and 1914. It appears that a change occurred in the regimen of the river sometime in 1928-1929, which affected the capacity of the Galop Rapids. What caused the apparent change is not known. In response, discharge measurements were made at the Three Points Section near Iroquois, Ontario, to check the stage-discharge equations being used.

In support of a diversions study (the nature of which was not retrieved from the survey document) being made during this period, discharge measurements were also taken in the South Sault Channel.

All measurements were made by personnel from the U.S. Lake Survey District.



St. Lawrence River, 1935 Leishmans Point Section Location

Figure 7-2

7.6.2 Description of Sections.

The **Three Points Section** was recovered from past surveys. The same 17 panels were used for this survey as were established previously. Between June 10 and September 1, 1936, 32 discharge measurements were made.

The **South Sault Section**, which was established about half a mile below Tracy's Landing, was divided into 4 panels. Twenty measurements were made during the period July 29 and August 5, 1936.

For the approximate location of the Three Points Section, see Figure 7-1. A map showing the location of the South Sault Section was not recovered.

7.6.3 Measurement Techniques.

The Three Points Section was re-sounded. Because the resulting profile did not differ from the soundings made for past surveys, the panel areas were selected the same as those determined for the 1900 survey. Four observations of vertical velocity distribution were made at each station. The resulting vertical velocity curve showed no change in the vertical coefficient from the 1900 survey. Changes in the transverse velocity distribution between 1900 and 1936 were minor.

The South Sault Section was lead-line sounded. Three determinations of vertical velocity distribution were made at each section, with a few observations at intermediate points. Paths of floats were followed to determine the angle between the direction of flow and the section line.

Discharge measurements at both sections consisted of a velocity reading at the 0.4 depth of each panel. Three Haskell meters, two Hoff meters and one Gettner meter were used to make all velocity measurements.

The water level gauges used at each section line were graduated boards as was an additional gauge at Tracy's Point in the South Sault Channel. For the duration of the hydraulic measurements, a Wilson self-registering gauge was maintained at Iroquois, Ontario, near Lock 25.

7.6.4 Discharge Computation.

In the reduction of the 1936 measurements at the Three Points Section, the coefficients developed by Shenehon in 1906, that related the mean panel velocity to the velocity at the panel index point, were used to determine panel discharges. For the South Sault Section, vertical and transverse velocity coefficients and directional coefficients were derived from measurements made for this survey. These coefficients were applied to the velocities measured at the panel index points and the panel areas to determine panel discharges. The total discharge through each section was the sum of the individual panel discharges.

The discharge measurements resulting from this survey are summarized in Tables 7.18 and 7.19 (see Appendix C). The report documenting this project is located in the U.S. Lake Survey District Archives, file number 3-2791 (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland). A copy of the report is also on microfilm, reel #162, at the Detroit District, Corps of Engineers, Detroit, Michigan.

7.7 Three Points Section, 1945.

7.7.1 Purpose.

The U.S. Lake Survey District, Corps of Engineers, conducted this survey to check the performance of the discharge rating curves being used at the time; when water levels on the river were high.

7.7.2 Description of Section.

The Three Points Section originated in 1900, was located on the St. Lawrence River, about 15 miles downstream from Ogdensburg, New York. The section was recovered from previous surveys; the use of 17 panels continued. Between July 3 and July 20, 1945, 22 discharge measurements were made through the section.

For the approximate location of the Three Points Section, see Figure 7-1.

7.7.3 Measurement Techniques.

The section was lead-line sounded; two crossings were also made with a sonic depth finder. The results were compared to the 1900 soundings and agreed closely, except near shore.

Twenty-two discharge measurements were taken at the section, using one Moore and three Haskell current meters. The measurements were made by lowering three of the meters, simultaneously, to the 0.4 depth of a panel at its index point.

The section gauge for this survey was a temporary board gauge positioned approximately 25 feet above the line of the section. During the time of measurement, water levels were also being gathered at the Ogdensburg and Iroquois recording gauges.

7.7.4 Discharge Computation.

The panel areas used to compute the discharges for the 15 interior panels were the same as those determined in 1900. For the end panels, panel areas were determined from the 1945 soundings. As with the previous surveys of the Three Points Section, all data were reduced using coefficients determined in 1906. Table 7.20 (see Appendix C) summarizes the resulting measured discharges. A copy of the report resulting from this survey can be found in the U.S. Lake Survey District Archives, file number 3-3081 (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland). A copy of the report is also on microfilm, reel #166, at the Detroit District, Corps of Engineers, Detroit, Michigan. Data are also stored in the U.S. Lake Survey District Archives, files 2-9227 to 2-9229.

7.8 Three Points Section, 1953.

7.8.1 Purpose.

This survey served several purposes. In addition to supplementing the data base supporting the stage-discharge relations in use at the time, this survey was made to measure the river flow after demolition operations were completed at the Gut Dam site. Also, as part of this survey, two alternative methods of measuring river discharge were tested. One technique, a short-cut method, involved measuring the entire section flow by metering at only one point. The second method was tried as a possible technique for measuring discharge during the winter, using floats. Work was done by the staff from the U.S. Lake Survey District, Corps of Engineers.

7.8.2 Description of Section.

First established in 1900, the Three Points Section was located approximately 1 1/2 miles below Iroquois, Ontario. The Section was divided into 17 panels. Between June 22 and July 16, 1953, 12 discharge measurements were made incorporating each of the 17 panels. During the same period, 15 measurements were made by metering only panel number eight.

For the approximate location of the Three Points Section, see Figure 7-1.

7.8.3 Measurement Techniques.

The section was sounded and the results were compared to previous soundings. The profile did not significantly differ from that of the last survey in 1945; therefore, the panel areas used in the discharge reduction were the same as those determined from previous surveys.

Water levels at the time of the survey were recorded at permanent automatic recording gauges located at Ogdensburg, New York, and Iroquois, Ontario. A temporary recording gauge and a staff gauge were installed at the section.

Seven meters were used at various times during the metering of this section. They included one Gettner, three Haskell and three Price current meters. Ten discharge measurements were made by metering at the 0.4 depth of each of the 17 panels. Two measurements were made by metering at the 0.2, 0.4, 0.6 and 0.8 depths of each panel, to enable comparison with Canadian practices. An additional 15 measurements made using the short cut method, where observations were made only at the 0.4 depth of panel 8, the center point of the section line.

To investigate a method for the determination of discharge past the section during the winter, a series of float observations were made at the same time that the one panel measurements (shortcut method) were being made. A secondary section line was established 100 feet downstream of the main section line. Floats were introduced at a given point upstream of the section line. They were allowed to drift down past both section lines. The time it took the float to pass from the main line to the secondary line was recorded. One hundred and eighty such observations were made.

7.8.4 Discharge Computation.

For the measurements made at all 17 panels, vertical velocity and directional coefficients determined from the 1900 survey were used to compute discharges. Transverse velocity coefficients were based on the observations made for this current survey. For the 15 measurements where readings were made only at the sections' midpoint, an empirical coefficient derived from past measurements was applied to the product of the area of the section and the observed velocity, to give the total river discharge. Tables 7.21 and 7.22 (see Appendix C) summarize the resulting measured discharges.

This survey is documented in the U.S. Lake Survey District Archives, file 3-3425 (available at the U.S. National Oceanic and Atmospheric Administration/National Ocean Service, Silver Springs, Maryland). A copy of the report can also be found in the microfilm files, reel #198, of the Great Lakes Hydraulics and Hydrology Branch, Detroit District, Corps of Engineers, Detroit, Michigan.

7.9 Three Points Section, 1953-1954.

7.9.1 Purpose.

Variations in the past results obtained from discharge measurements made by United States and Canadian agencies working independently, indicated the desirability of conducting a series of measurements by agencies of both countries working together. A stream measurement program on the St. Lawrence River at the Three Points Section was begun on

December 15, 1953 and completed on June 11, 1954. This program was designed to determine the difference in the results obtained using Canadian and United States flow measurement methodologies. Specifically, a comparison was made between results obtained using Price meters (Canada) versus Haskell meters (U.S.), and by measuring velocities at the 0.2 and 0.8 depths (Canada) or at the 0.4 depth only.

Personnel for the work were provided by the Canadian Department of Northern Affairs and National Resources, with observers from the Hydro-Electric Power Commission of Ontario, and the U.S. Lake Survey District, Corps of Engineers. Equipment was provided by all three agencies.

7.9.2 Description of Section.

The Three Points Section was re-established from previous surveys made by the U.S. Lake Survey District. The section spanned the St. Lawrence River just below Iroquois, Ontario, approximately 1,500 feet above Pinetree Point and the confluence of Parlow Creek. Sixty-five discharge measurements were made at this 17 panel section, between December 21, 1953 and June 2, 1954.

For the approximate location of the Three Points Section, see Figure 7-1.

7.9.3 Measurement Techniques.

Manual soundings were taken at 5-foot intervals, using 100-pound lead weights. Soundings were also made with an echo sounder. The echo sounder was later found to be out of adjustment; therefore, these soundings were not used to reduce the discharge measurements.

To establish vertical velocity curves for the various panels, an average of 18 measurements were made at each tenth of the depth at the metering point of each panel.

Discharge measurements were made at the 0.4 depth, using both Price and Haskell velocity meters, in order to compare the results obtained by the two different types of meters. Measurements were also made simultaneously at the 0.2, 0.4 and 0.8 depths, using Price meters alone, so that comparisons could be made between discharges computed from velocities at the 0.2 and 0.8 depths and those computed using the velocities recorded at the 0.4 depth.

For vertical control, water levels were recorded at Lock 25 (upstream of the section) and at the section, using automatic recording water level gauges. The gauge at Lock 25 was referenced to the permanent bench mark "Lock 25" at elevation 236.811 feet on the 1903 Datum (236.211 feet; IGLD 1955). The section gauge, referenced to bench mark SL15 (270.503 feet; 1935 Datum), was originally placed 1,000 feet upstream of the section on the U.S. shore. On March 3, 1954, it was moved to a point 475 feet above the section.

The direction of flow past the section was determined by noting the path of floats crossing the section.

7.9.4 Discharge Computation.

The results of manual soundings were plotted to obtain a profile of the section, from which panel areas were determined.

Vertical velocity coefficients were determined for each panel from the velocity measurements made at each tenth depth. The mean value of the velocity, measured at the index point during the entire measurement in the vertical section, was assigned the value of 100%. It was assumed that the velocity of the entire vertical section varied percentagewise as did the velocity at the index point. This theory was developed by the U.S. Lake Survey District. The velocities observed individually at each point on the vertical section were increased or decreased by the same percentage as the percentage change in velocity observed at the index point. By this means, all the velocities in the vertical were reduced to the same basis, as though all were measured simultaneously. The percentage relationship of the velocity at each point to the velocity at the index point was determined. A plot of these various percentages was made and the area under each curve computed. The vertical velocity coefficient for a particular depth was derived by dividing the area under the curve by the depth. The observed velocity at the index point multiplied by this vertical coefficient gave the mean velocity of the vertical section passing through the center of the panel. A coefficient to be applied to the 0.2 and 0.8 depth velocity observations was computed on the basis of the percentage relationship of the observations taken at the 0.2 and 0.8 depths to the observations taken at 0.4 depth.

The areas of the panels as determined from the profiles were adjusted using the directional, vertical and, where required, the transverse velocity coefficients to give adjusted area tables for the cross-section over a range of water surface levels from 226.50 to 230.80 feet. Separate tables were required for measurements taken at the 0.4 depth and for measurements taken at the 0.2 and 0.8 depths. Discharge in each panel was computed by multiplying the measured velocity by the adjusted area of the panel for the water level at the time of measurement. The section discharge was the sum of the individual panel discharges.

A copy of the report documenting this survey is on file with the Water Survey of Canada, Water Resources Branch, Environment Canada. A copy has also been placed in the Corps of Engineers, Detroit District Archives of the Great Lakes Hydraulics and Hydrology Branch, file 3-3425. The discharge measurements are summarized in Table 7.23 (see Appendix C).

7.10 Weaver Point Section, 1954-1955.

7.10.1 Purpose.

Construction of the hydroelectric portion of the St. Lawrence Seaway Development Project began in August 1954. Prior to this time, the St. Lawrence River flow was primarily determined from a stage-discharge relationship based on discharge measurements made at the Three Points Section. Channel changes resulting from the construction rendered the Three Points Section invalid. For that reason, a new metering section was established at Weaver Point. Discharge measurements were made at this section from August 1954 to August 1955.

The measuring program was carried out by the Water Resources Branch, Department of Northern Affairs and National Resources, in cooperation with the St. Lawrence Seaway Authority, the Department of Transport and the Hydroelectric Power Commission of Ontario. The field party included representatives from Ontario Hydro and from the U.S. Lake Survey District, Corps of Engineers.

7.10.2 Description of Section.

The Weaver Point Section was located about 5-1/2 miles downstream of Morrisburg, Ontario. The section extended from the Canadian shore at Weaver Point to the U.S. shore at what is now the Wilson Hill Wildlife Management Area. The section was divided into 18 panels, for measurement purposes. Between August 14, 1954 and August 4, 1955, 131 discharge measurements were made at this section.

The approximate location of this discharge measurement section is shown on Figure 7-1.

7.10.3 Measurement Techniques.

The section was lead-line sounded on three different occasions: August 10, 1954, June 28 and August 6, 1955. Echo soundings were also made 100-feet upstream and downstream of the section line, on July 24, 1954.

The direction of flow at the section was measured at the 0.2, 0.6 and 0.8 depths using a special instrument. This instrument consisted of an electrically driven gyro encased in a water tight shell. An attached dial located in the catamaran indicated instantaneous current direction.

To record water surface elevations, gauges were placed near the section on both the Canadian and U.S. shores. An automatic water level recorder and a staff gauge were installed on the U.S. shore and referenced to bench mark No. 8 (elevation 259.790 feet;

1935 Datum). A chain gauge was used on the Canadian side, referenced to bench mark 901A (elevation 257.844; 1935 Datum).

Gurley Price pattern 622 and 623 meters were used to make the summer, or open water, velocity measurements. The larger pattern 600 Price meters were used for the winter measurements, because of their rugged construction. The meters were rated several times, during the course of this project. It was found that the larger Price meters could not be relied upon to retain their ratings to the same degree as the smaller meters.

Vertical velocity measurements were made by metering at each tenth of the depth. Three meters were placed at the same depth and observations were made for an average of 3 minutes per measurement, except at the 0.2, 0.6 and 0.8 depths, where observations were made for an average of 6 minutes per measurement.

The major portion of the discharge measurements were made by taking velocity readings at the 0.2, 0.6 and 0.8 depths. Three discharge measurements were metered only at the 0.6 depth.

7.10.4 Discharge Computation.

The Weaver Point discharges were computed using adjusted standard area tables. Two tables were constructed, one for use with the 0.2, 0.6 and 0.8 depths method of observation and one for the 0.6 depth method. The tables gave adjusted areas for each panel at 0.1 foot increments of stage, at the section gauge on the U.S. side. The adjusted panel areas incorporated vertical and transverse velocity coefficients, directional coefficients and a slope correction coefficient.

The vertical velocity coefficients were determined from curves drawn using the average observed velocity at each tenth depth of a panel, expressed as a percentage of the mean of the velocities at the 0.2, 0.6 and 0.8 depths. The area under each curve represented the coefficient to be applied to the mean of the velocities observed at the three depths to give the mean velocity in the vertical. Vertical velocity coefficients for discharge measurements made only at the 0.6 depth, were determined from curves where each tenth depth was expressed as a percent of the velocity at the 0.6 depth.

The transverse velocity coefficient adjusts the mean velocity at the observation station (generally the center of the panel) to take care of variations in velocity transversely across the panel. They were determined from curves which plotted the mean of the velocities observed at the 0.2, 0.6 and 0.8 depths. The areas under the curves were calculated and a mean coefficient determined for each panel. This coefficient, when multiplied by the mean velocity in the vertical, gave the mean velocity for the panel.

Directional coefficients were determined for each observation station from the mean of the angles of flow at the 0.2, 0.6 and 0.8 depths. For the three discharge measurements using the 0.6 method of observation, coefficients were obtained from observations at the 0.6 depth only.

A slope correction was determined for each panel, to allow for the difference in stage at the two section gauges.

The results from this discharge measurement project are summarized in Table 7.24 (see Appendix C). The report documenting this survey is on file with the Water Survey of Canada, Water Resources Branch, Environment Canada. A copy of this report is also in the Archives, file 3-3425, of the Great Lakes Hydraulics and Hydrology Branch, Detroit District, Corps of Engineers, Detroit, Michigan.

7.11 Massena Point Section, 1960.

7.11.1 Purpose.

Ontario Hydro and the Power Authority of the State of New York, in response to a request from the International St. Lawrence River Board of Control, arranged to have the Water Resources Branch, Department of Northern Affairs and National Resources, and the U.S. Lake Survey District, Corps of Engineers, conduct discharge measurements on the St. Lawrence River downstream of the Barnhart powerhouses. The purpose of these measurements was to check the discharge computed using the Moses-Saunders powerhouse turbine ratings.

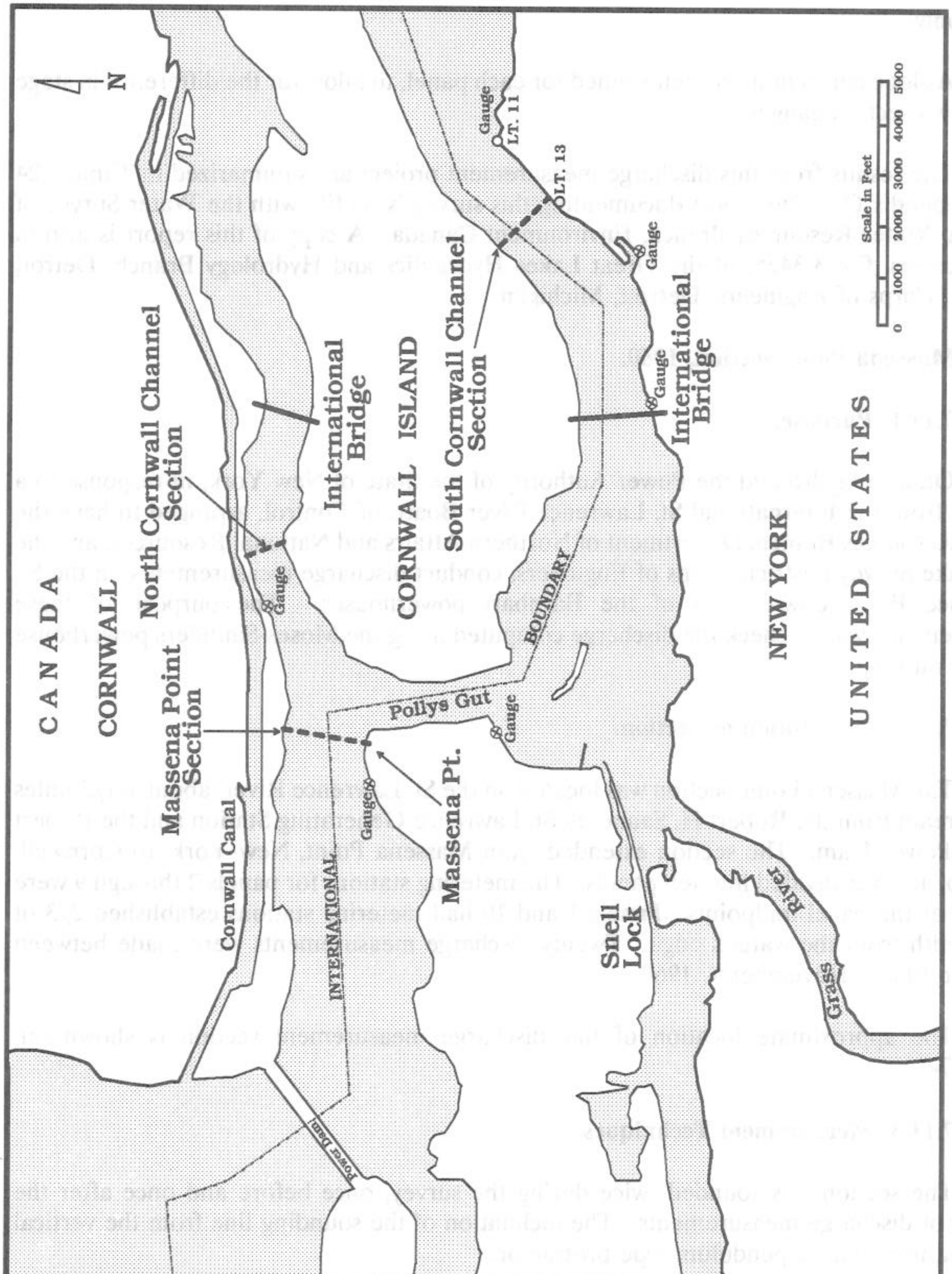
7.11.2 Description of Section.

The Massena Point Section was located on the St. Lawrence River, about 1-1/2 miles downstream from the Robert H. Saunders-St. Lawrence Generating Station and the Robert Moses Power Dam. The section extended from Massena Point, New York, to Cornwall, Ontario, and was divided into ten panels. The metering stations for panels 2 through 9 were located at the panel midpoints. Panels 1 and 10 had metering stations established 2/3 of their width from the water's edge. Twenty discharge measurements were made between October 10 and November 4, 1960.

The approximate location of this discharge measurement section is shown on Figure 7-3.

7.11.3 Measurement Techniques.

The section was sounded twice during the survey, once before and once after the making of discharge measurements. The inclination of the sounding line from the vertical was measured with a pendulum type protractor.



St. Lawrence River, Massena Point and North and South Cornwall Channel Section Locations

Figure 7-3

The instruments used to measure the discharge were the Gurley-Price current meters. These were rated prior to and after the survey. For each measurement, velocity observations of three minutes duration were recorded at every tenth depth of each panel, using three meters lowered simultaneously to different depths of the panel. Measurements were also made at the 0.6 depth for positions located about 45 feet from the south shore, and 60 and 140-feet from the north shore. The purpose of these measurements was to establish the transverse velocity curve between the end panel metering stations and the shore.

Water surface elevations used in the discharge calculations were obtained from records at water level recorder H-26CA. This recorder, installed and maintained by Ontario Hydro, was located on the U.S. shore, about 300 feet upstream from the section.

The direction of flow past the section was obtained using wooden floats, weighted at one end. A float was placed in the river, about 500 feet upstream from the section, and allowed to float freely 750 feet downstream. The float position was obtained during its journey, at time intervals of about 15 seconds by angular fixes from transits on shore. The position of float lines were gathered at intervals of about 70 feet across the river.

7.11.4 Discharge Computation.

Vertical velocity curves for each observation station were drawn from the mean of the velocity observations, taken at each tenth depth for each of the twenty discharge measurements. For each panel, vertical velocity coefficients were derived from the curve for the 0.1, 0.4 and 0.7 depths, the 0.2, 0.5 and 0.8 depths and the 0.3, 0.6 and 0.9 depths. For each measurement at each panel, the vertical velocity coefficients were applied to the averages of the corresponding observed velocities. The resulting three velocity values were then averaged to give a mean velocity for that panel for that measurement.

Based upon the mean velocities at the metering stations and the mean observed velocities at the three additional positions near shore, a transverse velocity curve was drawn. The transverse velocity coefficient for each panel was then calculated as the ratio of the velocity in the panel under the transverse velocity curve to the mean velocity determined from the vertical velocity curve at the station.

To determine a directional coefficient from the results of the float survey, flow direction lines were drawn. From these plots, the angle between the flow lines and the section line was determined for each panel. The sine of this angle became the directional coefficient used to convert observed velocity readings to velocities normal to the section.

The discharge through each panel was computed by multiplying the panel area, the average of the three meter runs (each reduced to mean velocity in the vertical), the transverse coefficient and the directional coefficient. The panel discharges were then summed to get a discharge for the entire section for that measurement. A summary of the results of the discharge measurements can be found in Table 7.25 (see Appendix C). A copy of the report written as a result of this survey can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, file number 3-3916, of the Detroit District, Corps of Engineers, Detroit, Michigan.

7.12 Massena Point and North Cornwall Channel Sections, 1970.

7.12.1 Purpose.

With the completion of the St. Lawrence Seaway in 1959, ships began experiencing navigational difficulties in the South Cornwall Channel of the St. Lawrence River, between the International Bridge and the Snell Lock. In this vicinity, the total flow of the St. Lawrence River passing through the Moses-Saunders hydroelectric plants is split by Cornwall Island.

The St. Lawrence Seaway Corporation wished to obtain a measure of the distribution of flow around Cornwall Island; therefore, in cooperation with the St. Lawrence Seaway Authority of Canada, they requested the U.S. Lake Survey District, Corps of Engineers, and the Department of Energy, Mines and Resources, Water Survey of Canada, to undertake a joint program of discharge measurements. The U.S. Lake Survey District was assigned to measure the total discharge of the river at the Massena Point Section, and the Water Survey of Canada was to meter the channel north of Cornwall Island.

7.12.2 Description of Sections.

The **Massena Point Section** was located on the St. Lawrence River about 1-1/2 miles downstream from the Moses-Saunders Powerhouses. The Section extended from Massena Point, New York, to Cornwall, Ontario. For this assignment, the section was recovered from the survey previously made in 1960. As in the 1960 survey, the section was divided into ten panels. Thirty-one discharge measurements were made between May 7 and May 23, 1970.

The **North Cornwall Channel Section** was located about 3,700 feet below the Massena Point Section or about 11,500 feet below the Moses-Saunders power plants. It extended across the channel from Cornwall Island to the City of Cornwall, Ontario. The section had a total width of 1,200 feet and was divided into twelve panels. Thirty-one discharge measurements were made between May 7 and 23, 1970.

The approximate locations of these discharge measurement sections are shown on Figure 7-3.

7.12.3 Measurement Techniques.

A drogue study, similar to that performed in 1960, was repeated at the Massena Point Section. The direction of flow survey conducted at the North Cornwall Channel Section used a weighted plywood drogue suspended at the 0.6 depth from a float. The float was tracked by two transits on the northern shore. The North Cornwall Channel Section was then laid out to be normal to a majority of the flow lines. As a result, all panels except panels 10 and 11 had a directional coefficient of unity.

Both sections were lead-line sounded before discharge measurements were made, in order to develop a cross sectional profile from which panels could be determined. The soundings were confirmed using an echo sounder. To determine the cross sectional area at the time of each measurement, water levels were recorded at section gauges during the periods of measurement. The Massena Point Section gauge, located on Barnhart Island, was an automatic digital gauge installed in a gauge well of the abandoned H-26C gauge site, used during the construction of the Seaway. The North Cornwall Channel Section gauge was a Fisher Porter punch tape recorder set up on the south shore of the channel, about 180 feet below the section.

As mentioned previously, the Massena Point Section was metered by the U.S. Lake Survey District and the North Cornwall Channel Section was metered by the Water Survey of Canada. Thirty-one measurements were made simultaneously at both sections, between May 7 and 23, 1970. Twenty-eight of the measurements were taken during periods of peak plant load and three measurements (numbers 23, 27, 29) during off-peak periods, in the early morning.

Discharge measurements at the Massena Point Section were obtained using four Price current meters attached to 100-pound weights and suspended individually from a 21-foot cathedral hulled vessel. At each panel measuring station, the velocities were measured at each tenth depth in three settings of three meters. The fourth meter was kept at the 0.4 depth as an index for adjusting the velocities from the three settings to a common base. Similar methodology was employed to measure at the North Cornwall Channel Section.

7.12.4 Discharge Computation.

The discharge measurements made at the Massena Point Section were reduced by the U.S. Lake Survey District, and those at the North Cornwall Channel Section by the Water Survey of Canada. At the North Cornwall Channel Section, discharges were manually computed. The eight point velocities in each panel were averaged to obtain the mean vertical velocity at the panel point. At panel 12, the one observation was considered to be the mean vertical velocity. The mean vertical velocity was multiplied by transverse and directional coefficients and by the panel area to obtain the panel discharge. The transverse velocity coefficients were determined from a curve based on the average velocities for all the measurements at the North Cornwall Channel Section.

At the North Cornwall Channel Section, all panels, except one, were metered from a catamaran positioned at the panel midpoint. Panel 12 was measured by wading to the midpoint. Velocity observations for discharge measurements were made at eight depths, using four Price current meters suspended simultaneously. At Panel 12, velocity observations were made only at the 0.7 depth. The discharge for the measurement was the sum of the panel discharges.

The U.S. Lake Survey District used a discharge reduction program to reduce the data from the Massena Point Section. Following all field operations, the data recorded on field data forms, together with the directional coefficients, panel configurations, computed areas and stage height information were keypunched and processed through a digital computer. A brief description of a similar computer program may be found in Appendix A.

The data and results of this survey can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, files numbered GLHH 77-6 A and B, of the Detroit District, Corps of Engineers, Detroit, Michigan. A summary of the resulting discharges may be found in Table 7.26 (see Appendix C).

7.13 Wolfe Island Sections, 1972.

7.13.1 Purpose.

As part of a heat flux study for the International Field Year for the Great Lakes (IFYGL), the Detroit District, Corps of Engineers, Great Lakes Hydraulics and Hydrology Branch, was requested by the Lake Survey Center, National Oceanic and Atmospheric Administration (NOAA), to make flow distribution measurements around Wolfe Island, Ontario. Between May 1 and May 15, 1972, discharge measurements were made at two sections, one located north and the other located south of the island.

7.13.2 Description of Sections.

The **Wolfe Island-North Section** was located on the St. Lawrence River, north of Wolfe Island, Ontario. The section extended from a peninsula on Wolfe Island, called Abraham's Head, to the Canadian mainland. The section was 5,477 feet in length and was divided into four panels. The metering stations of the two end panels were located 2/3 of their respective panel widths from shore. The panel points of the two interior panels were located at the midpoints. During the period May 4 to May 15, 1972, six discharge measurements were made.

The **Wolfe Island-South Section** extended from Cedar Point State Park, New York, on the U.S. mainland, across the St. Lawrence River to the south shore of Wolfe Island, a distance of about 4,438 feet. The section was divided into four panels. The metering stations of the end panels were located 2/3 of the panel widths from shore. The panel points of the other two panels were at the panel midpoints. From May 3 to May 15, 1972, six discharge measurements were made.

The approximate locations of these discharge measurement sections are shown on Figure 7-4.

7.13.3 Measurement Techniques.

A drogue study was made at the Wolfe Island-South Section, on April 29, 1972. Ten drogue runs were made, seven at a depth of 60 feet and three at 15 feet.

Both sections were lead-line sounded prior to making the discharge measurements.

Two-minute velocity readings were made at the 0.2, 0.4, 0.6 and 0.8 depths of each panel, using a Savonious current meter. The meter was capable of giving both current direction and current velocity.

7.13.4 Discharge Computation.

The data from the drogue and velocity/temperature studies were reduced by the Detroit District, Corps of Engineers, and provided to the Lake Survey Center, NOAA, the agency responsible for the analyses of the data. The computed results were retained by the Lake Survey Center. The raw data may be found in the Corps' Great Lakes Hydraulics and Hydrology Branch Archives, file number GLHH 72-5, of the Detroit District, Detroit, Michigan.

7.14 Massena Point Section, 1972.

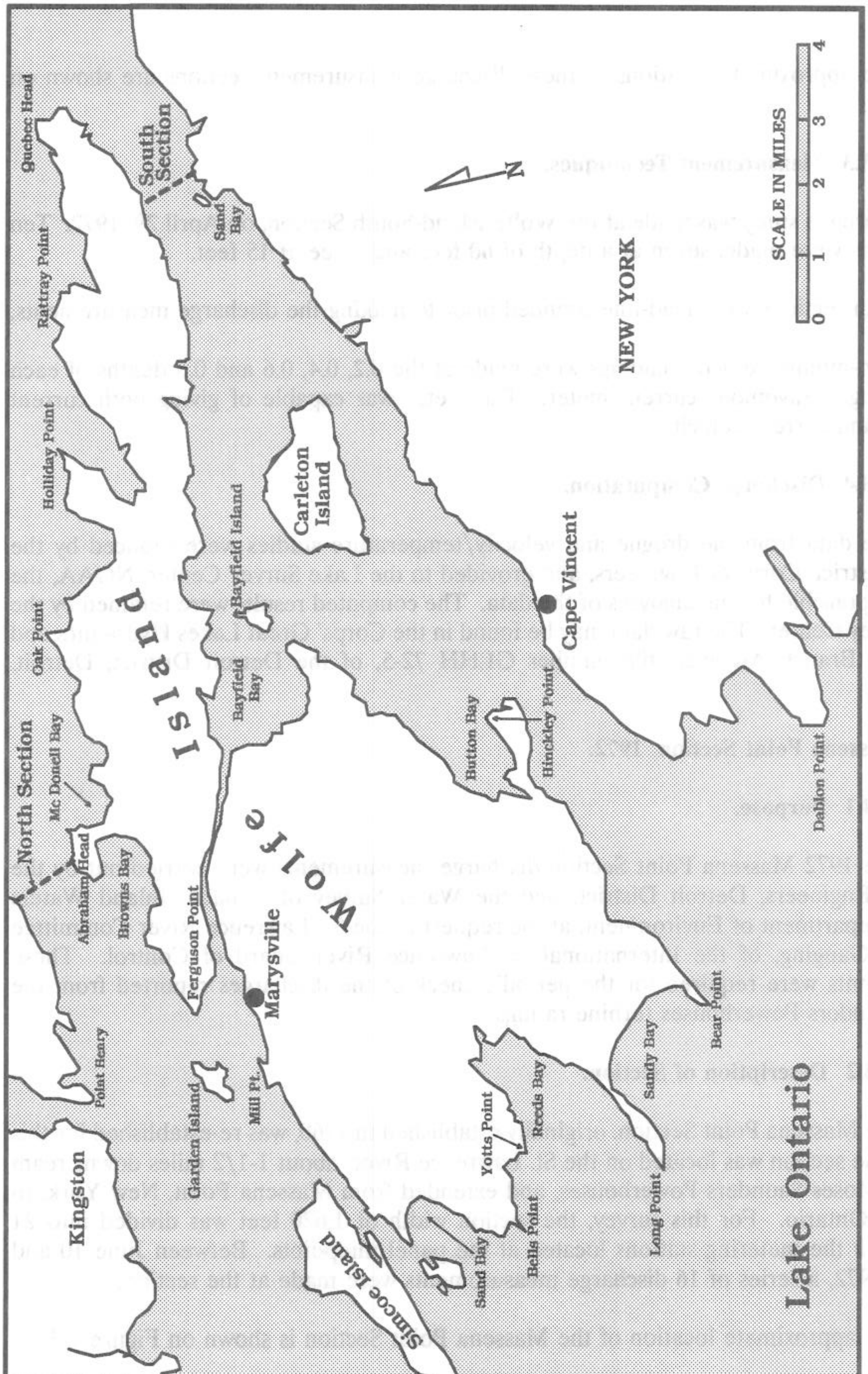
7.14.1 Purpose.

The 1972 Massena Point Section discharge measurements were carried out by the Corps of Engineers, Detroit District, and the Water Survey of Canada, Inland Waters Branch, Department of Environment, at the request of the St. Lawrence River Committee on River Gauging, of the International St. Lawrence River Board of Control. These measurements were required for the periodic check of the discharges reported from the Moses-Saunders Powerhouses turbine ratings.

7.14.2 Description of Section.

The Massena Point Section, originally established in 1960, was re-established for this survey. The section was located on the St. Lawrence River, about 1-1/2 miles downstream from the Moses-Saunders Powerhouses, and extended from Massena Point, New York, to Cornwall, Ontario. For this survey, the section width of 1,620 feet was divided into 21 panels, with the metering stations located at the panel midpoints. Between June 10 and June 19, 1972, a series of 16 discharge measurements were made at the section.

The approximate location of the Massena Point Section is shown on Figure 7-3.



St. Lawrence River, Wolfe Island Section Locations

Figure 7-4

7.14.3 Measurement Techniques.

To determine the panel sizes, soundings were made across the section at intervals of about 40 feet, using a 100-pound metering weight. At these sounding locations, the velocities at the 0.2 and 0.8 depths were measured. A unit-discharge plot was made, using the resultant average velocities times the depths. From this plot, the section was divided into 21 panels, such that no panel would discharge more than 8% of the total flow.

The cross-sectional profile of the Massena Point Hydraulic Section was determined from the average of five echo sounding profiles along the section line. The lead-line soundings used to define the panels were not used in the determination of the profile. The section gauge used to determine areas at the time of the discharge measurements was located on the U.S. shore at the original H-26 CA gauge site, upstream of the section.

Prior to making discharge measurements, 26 drogues were tracked past the section to determine the direction of flow. The vanes of these drogues were set at 0.5 to 0.6 of the depth. This survey showed that the major portion of the flow was perpendicular to the section. At the conclusion of the discharge measurements, the direction of flow was sampled at each tenth depth at each measuring point, using an instrument called a velocity azimuth depth assembly. The results of these measurements indicated that there were no measurable differences in the direction of flow in the vertical at any of the stations.

Two survey vessels were used simultaneously (starting at opposite ends of the section line) to measure the discharge through the section. Each metering vessel utilized four Price-type current meters suspended on 100- pound metering weights. For each measurement, three meter settings were made at each panel. One meter was kept at a constant 0.4 depth for all three settings. The remaining three meters were set at the 0.3, 0.6 and 0.9 depths for the first setting, 0.2, 0.5 and 0.8 for the second and at the 0.1, 0.4 and 0.7 depths for the last setting. Two-minute velocity readings were made at each tenth depth.

Each of the metering parties independently completed an entire measurement (all 21 panels) on each day of metering. Eight measurements were completed by each party, for a total of 16 discharge measurements at the section.

7.14.4 Discharge Computation.

The data collected during this survey were reduced using the Detroit District, Corps of Engineers, discharge measurement program. A brief description of the procedures used in the program is given in Appendix A. The data and results of this survey can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, files numbered GLHH 73-1 A and B, of the Detroit District, Corps of Engineers, Detroit, Michigan. Table 7.27 (see Appendix C) lists the discharge values that resulted from this survey.

7.15 Iroquois Dam Section, 1972.

7.15.1 Purpose.

In July 1972, as part of the International Field Year for the Great Lakes (IFYGL), Terrestrial Water Budget program, simultaneous measurements of Lake Ontario inflow and outflow were made. The purpose of the measurements was to provide information with which to evaluate the terrestrial water budget and the accuracy of existing methods of determining the inflow and outflow of Lake Ontario.

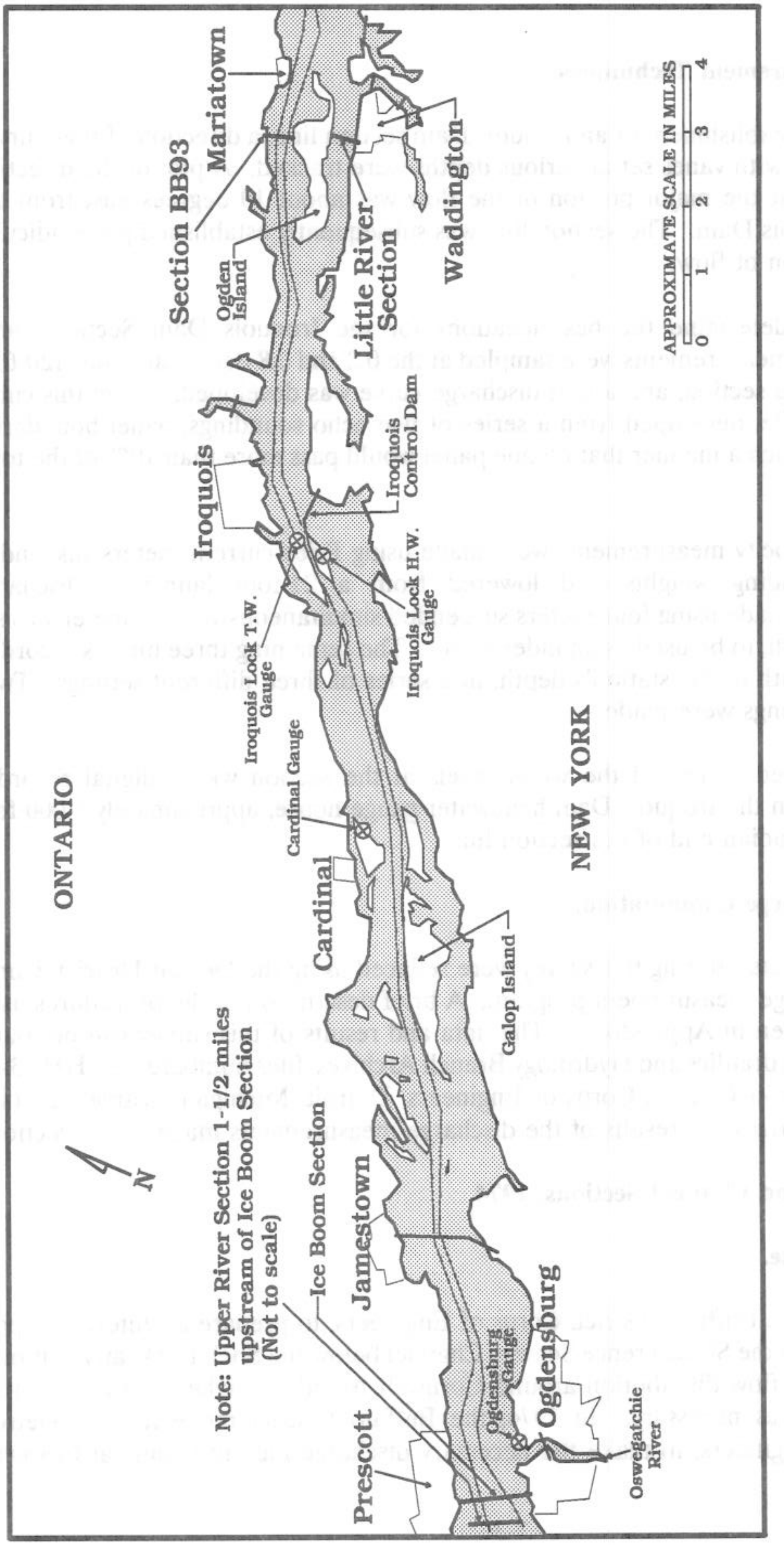
This project was a joint effort undertaken by the Water Survey of Canada, Environment Canada, and the Detroit District, Corps of Engineers. The Water Survey of Canada made measurements at the Stella Niagara hydraulic section on the Niagara River, in order to evaluate Lake Ontario inflow. These measurements are documented in Section 6. The Corps of Engineers made an assessment of the Lake Ontario outflow by taking discharge measurements at the Iroquois Dam Section on the St. Lawrence River. In addition to these measurements, the Corps measured the flow of the Oswegatchie River into the St. Lawrence River, above the Iroquois Dam Section. The Canadian crew also calibrated the flow through the DeCew Falls hydroelectric installation, which utilizes the flow from the Welland Canal diversion into Lake Ontario. The documentation of the latter two sets of measurements is not included in this report. Data are retained in the associated archives of the two agencies involved.

7.15.2 Description of Section.

The Iroquois Dam Section was selected as the measuring site on the St. Lawrence River, since it afforded the best location from which to measure Lake Ontario outflow. The Oswegatchie River is a significant tributary of the St. Lawrence River, between Lake Ontario and the Iroquois Dam, and so it was necessary to also rate the flow of that river; not documented in this report. The outflow from Lake Ontario was considered to be the flow at Iroquois Dam minus the local inflow of the Oswegatchie River.

The Iroquois Dam Section was located on the St. Lawrence River, about 500 feet upstream of the Iroquois Dam and extends from the U.S. shore north to the Canadian shore. The section was divided into 15 panels. The measuring stations of the two end panels were positioned at a point about 2/3 of the panel's width from the water's edge. The metering stations of the remaining 13 panels were located at the panel midpoints. A total of 34 complete measurements were made at this section, between July 6 and July 28, 1972.

The approximate location of the Iroquois Dam Section, about 500 feet upstream of the Iroquois Dam, is shown in Figures 7-1 and 7-5.



St. Lawrence River, Iroquois Dam, Little River, BB93, Upper River and Ice Boom Section Locations

Figure 7-5

7.15.3 Measurement Techniques.

Prior to the establishment of an Iroquois Dam section line, a direction of flow survey was made. Drogues with vanes set at various depths were tracked. A plot of the direction of flow indicated that the major portion of the flow was about 10 degrees east from the normal to the Iroquois Dam. The section line was subsequently established perpendicular to the major direction of flow.

In order to determine the best locations for the Iroquois Dam Section panel boundaries, velocity measurements were sampled at the 0.2 and 0.8 depths at about 120-foot increments across the section, and a unit discharge curve was developed. From this curve and the section profile, developed from a series of five echo soundings, panel boundaries were established in such a manner that no one panel would pass more than 10% of the total flow.

All of the velocity measurements were made using Price current meters suspended on 100-pound sounding weights and lowered from a 21-foot launch. Discharge measurements were made using four meters suspended simultaneously. One meter was set at a constant 0.4 depth, to be used as an index meter. The remaining three meters recorded velocities at each tenth of the station's depth, in a series of three different settings. Two-minute velocity readings were made.

The gauge used to record the water levels at the section was a digital recorder temporarily located in the Iroquois Dam headwater gauge house, approximately 1,000 feet upstream of the Canadian end of the section line.

7.15.4 Discharge Computation.

The data collected during this survey were reduced using the Detroit District, Corps of Engineers, discharge measurement program. A brief description of the procedures used in the program is given in Appendix A. The data and results of this survey can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, files numbered GLHH 73-11 A and B, of the Detroit District, Corps of Engineers, Detroit, Michigan. Table 7.28 (see Appendix C) summarizes the results of the discharge measurements made at the section.

7.16 Cornwall Island Channel Sections, 1974.

7.16.1 Purpose.

In order for the Buffalo District, Corps of Engineers, to prepare an Interim Report for Safe Navigation in the St. Lawrence Seaway Channel below the Snell Lock, an additional determination of the flow distribution around Cornwall Island, at higher flows than those measured in 1970, was necessary. In 1974, the Buffalo District requested the Detroit District, Corps of Engineers, to make the necessary discharge measurements at Cornwall

Island. These measurements were taken while maintaining nearly constant discharge through the Moses-Saunders Powerhouses. The work was carried out with assistance from the Water Survey of Canada and support from the St. Lawrence Seaway Development Corporation.

7.16.2 Description of Sections.

The **North Cornwall Channel Section** was originally established in 1970 and was recovered for this survey. It was located on the North Cornwall Channel, between Pollys Gut and the International Bridge. The section extended about 908 feet across the channel from the Canadian mainland to Cornwall Island. The section was divided into 20 panels with all the metering stations located at the panel midpoints. A total of ten measurements were made between September 9 and September 14, 1974.

The **South Cornwall Channel Section** was newly established on the South Cornwall Channel downstream of the International Bridge and extended about 1,421 feet across the channel from the U.S. mainland to Cornwall Island. This section was divided into 20 panels. The metering stations of the two end panels were located about 2/3 of their panel widths from their respective shores. The remaining 18 metering stations were located at the midpoints of the panels. Between September 9 and September 14, 1974, eight discharge measurements were made at this section.

The approximate locations of these discharge measurement sections are shown on Figure 7-3.

7.16.3 Measurement Techniques.

Prior to establishing the South Cornwall Channel Section, a direction of flow survey was made. Drogues with vanes set approximately at mid-depth were tracked and a field plot was made. The section line was established perpendicular to the majority of the flow.

A thorough drogue survey was carried out at the North Cornwall Channel Section in 1970 and was used as the basis to compute the directional coefficients needed for this study. Additional drogue courses were observed with the vanes set at near bottom depths to determine whether any backflow existed in the reach.

A series of five echo soundings were taken at both sections and plots of the section profiles were developed. Panel areas were subsequently determined from the section profiles. During the period of discharge measurements, two temporary water level recording gauges were operated as section gauges for use in adjusting panel areas for fluctuations in stage. These gauges were provided by the St. Lawrence Seaway Development Corporation.

Velocities were sampled at the 0.2 and 0.8 depths at about 80-foot increments across the South Cornwall Channel Section and a unit-discharge curve developed. A unit-discharge curve had been developed for the North Cornwall Channel Section in 1970, and this curve was used again for this survey. From these curves, the panel boundaries of both sections were established in such a manner that no one panel would pass more than 8% of the total flow through the section.

Two vessels were used to simultaneously measure the North and South Cornwall Channel Sections. The two vessels were each equipped with four Price current meters, suspended on 100-pound sounding weights.

When discharge measurements were made, a vessel was positioned over the appropriate metering station and the current meters lowered. One meter was set at a constant 0.4 depth, as an index meter. In a series of three meter settings, the remaining three meters took readings at each of the nine tenth depths. If during a panel measurement, the nine vertical velocities did not appear as a smooth transition, or if the three index meter readings were not similar, it was assumed one or more of the readings were in error and the panel was remeasured. In this manner, the vertical velocity distribution was measured at each panel of a section.

7.16.4 Discharge Computation.

The data collected during this survey were reduced using the Detroit District, Corps of Engineers, discharge measurement program. A brief description of the procedures used in the program is given in Appendix A. The raw field data were also reduced, independently, by the Water Survey of Canada, thus providing a valuable check on the overall results of the discharge measurements.

The data and results of this survey can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, file number GLHH 74-14, of the Detroit District, Corps of Engineers, Detroit, Michigan. The results of the discharge measurements, made at the North and South Channel Sections in 1974, are summarized in Tables 7.29 and 7.30 (see Appendix C).

7.17 Little River, BB93, Upper River and Ice Boom Sections, 1976.

7.17.1 Purpose.

In August 1976, the Waterways Experiment Station, Corps of Engineers, made a request to the Detroit District, Corps of Engineers, for discharge measurements on the St. Lawrence River. The Waterways Experiment Station was conducting a model study in the area of Ogdensburg, New York, and Ogden Island. They wished to obtain information on the distribution of flow around Ogden Island and they wanted discharge measurements in the vicinity of the Ogdensburg-Prescott ice boom. At the time of the request, the Detroit District was conducting a velocity study in the area, in cooperation with the St. Lawrence

Seaway Development Corporation; the requested discharge measurements were incorporated into that project.

7.17.2 Description of Sections.

To measure the flow around Ogden Island, two hydraulic sections were established, the Little River Section and Section BB93. The **Little River Section** was located off the south side of Ogden Island and extended about 1,607 feet from the U.S. mainland at Waddington, New York, to Ogden Island, New York. This section was divided into ten panels.

Section BB93 was located on the north side of Ogden Island and extended from Ogden Island across the navigation channel to the Canadian mainland, a distance of about 1,770 feet. The section was divided into eleven panels. On August 6, 1976, one discharge measurement was made on both the Little River and BB93 Sections.

Two additional hydraulic sections, Upper River and Ice Boom, were established to measure the river discharge adjacent to the Ogdensburg-Prescott ice boom. Selected to coincide with the location of the boom, the **Ice Boom Section** was located upstream of the confluence of the Oswegatchie River and extended across the St. Lawrence River from Ogdensburg, New York, to Prescott, Ontario. The distance from the U.S. shore to the Canadian shore, at this point on the river, was about 5,354 feet. Near the U.S. shore, there is a shallow area with heavy weed growth that was considered dead water; so, the section proper began about 1,007 feet out from the U.S. shore and extended about 4,347 feet to the Canadian shore. The section was divided into ten panels. On August 14, 1976, one discharge measurement was made at this section.

The **Upper River Section** was established approximately 1-1/2 miles upstream of the Ice Boom Section, as a check of the discharge measurements made at the Ice Boom Section. This section extended from the U.S. shore to about 295 feet from the Canadian shore, at which point weed growth near the shore had stopped the flow of water, creating a 295-foot wide area of dead water. The remaining 6,372 feet of the section were divided into ten panels. One discharge measurement was made at this section, on August 13, 1976.

The approximate locations of these discharge measurement sections are shown on Figure 7-5.

7.17.3 Measurement Techniques.

The Sections were established in close proximity to existing horizontal and vertical control points. After first fixing a base line, the required section line was established perpendicular to the direction of the current. After setting up a given section line, the channel was echo sounded to determine the bottom profile. When making discharge measurements at a panel, the bow of the survey launch was positioned over the panel point and three Price current meters, suspended on 100-pound weights, were simultaneously lowered to the 0.2, 0.4 and 0.8 depths. Meter readings of four minutes duration were taken.

7.17.4 Discharge Computation.

The meter counts taken at each meter reading were converted to velocities using the meter rating equation of the appropriate meter. The panel velocity was the result of averaging the three velocity readings taken in a panel. Panel areas were derived by planimetering the cross-sectional profile constructed from the soundings. The panel area was multiplied by the mean panel velocity to determine the panel discharge. Individual panel discharges were summed to obtain the total section discharge.

Table 7.31 (see Appendix C) summarizes the discharge measurements taken at the four hydraulic sections. The raw data from this survey can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, file number GLHH 77-9, of the Detroit District, Corps of Engineers, Detroit, Michigan. A copy of the resulting report is located in file GLHH 77-11 of the same archives.

7.18 Raft Narrows Channel, Upper Narrows Channel, Light No. 227, Rift Narrows Channel and Cedar Point Sections, 1977.

7.18.1 Purpose.

The 1977 discharge measurements were made to obtain data in support of the development of a St. Lawrence River mathematical flow model. This project was undertaken by the Great Lakes Hydraulics and Hydrology Branch of the Detroit District, Corps of Engineers. The District contracted with the Great Lakes Environmental Research Lab (GLERL), NOAA, to develop a St. Lawrence River mathematical flow model.

7.18.2 Description of Sections.

The **Raft Narrows Channel Section** was established across the channel between the northeast end of Mitchell Point, Hill Island, Ontario, and the Canadian mainland; nearly perpendicular to the mean direction of flow in the channel. The section was divided into 10 panels. A series of 7 discharge measurements were made between August 17 and August 26, 1977.

The **Upper Narrows Channel Section** was established across the channel between the Towers Resort property on Wellesley Island, New York, and the U.S. mainland at the St. Lawrence Park, New York. The section was divided into 7 panels. A series of 7 discharge measurements were made between August 17 and August 26, 1977.

The **Light No. 227 Section** (Bartlett Point) was established across the channel from Barlett Point, New York, on the U.S. mainland to Murdock Point, New York, on Grindstone

Island. The section was divided into 10 panels. A series of 5 discharge measurements were made between August 19 and August 26, 1977.

The **Rift Narrows Channel Section** was established to span the channel at the Highway 81 bridge between Wellesley Island, New York, and Hill Island, Ontario. The section was divided into 5 panels. A series of 5 discharge measurements were made between August 17 and August 26, 1977.

The **Cedar Point Section** was established across the channel from Cedar Point State Park, New York, on the U.S. mainland, to the Wolfe Island shoreline, New York. The section was divided into 6 panels. One discharge measurement was made on August 25, 1977.

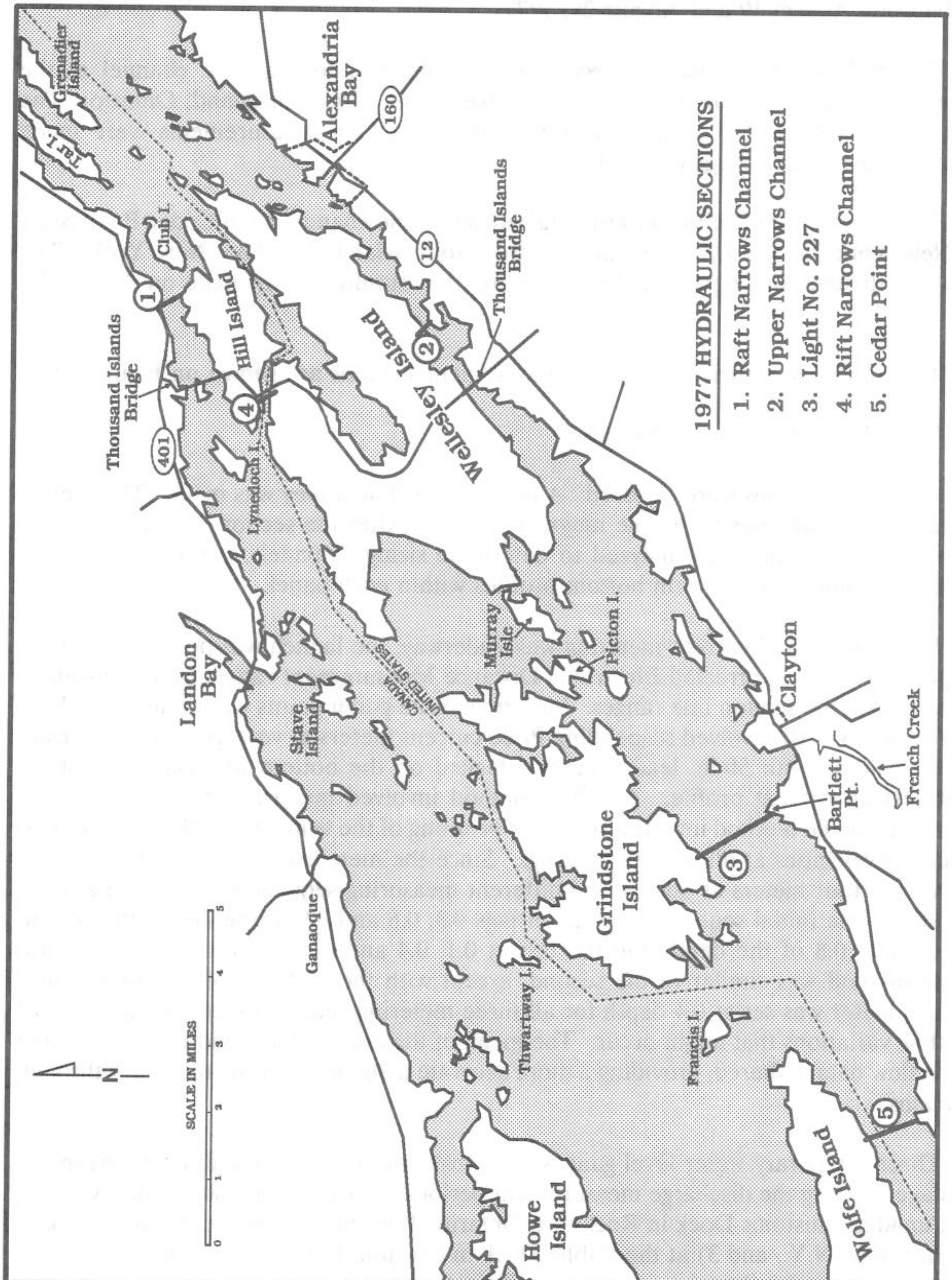
The locations of these discharge measurement sections are shown on Figure 7-6.

7.18.3 Measurement Techniques.

All of the sections were sounded. A direction of flow survey was made. The section lines were established normal to the majority of flow. After the section was sounded, the resultant bottom profile was analyzed to determine sizing of panels, based, as nearly as possible, on maintaining uniform bottom profiles within each panel.

When the actual current metering was underway, the launch was positioned on the panel point, using the corrected Electronic Distance Measurement values from the water's edge along with the section line ranges. Metering at the panel points was done using three distinct methods. All involved suspending Price current meters at various tenth-settings of the water column with 50-lb. lead weights attached on the bottom to ensure creating a straight vertical current profile. The first method involved metering at 0.2, 0.4 and 0.8 depths. The second method involved complete profiling of the velocities in the vertical; that is, acquiring velocities at all 0.1 - 0.9 settings. Since the metering could be achieved with no more than four meters at once, three different measuring sequences were used at each panel point. The initial sequence was at settings 0.3, 0.6 and 0.9 of the depth, the second at 0.2, 0.5 and 0.8 of the depth and the last at 0.1, 0.4 and 0.7 of the depth. The third metering method was similar to the second, except with the addition of an index meter. This index meter was set at 0.4 depth for all three metering sequences, providing a record of any flow variations that might occur. The mean of the index meter readings was applied to all the flow data gathered, providing a more accurate assignment of the total flow through the sections.

Three temporary water level gauges were installed to determine fluctuations in the water stages, during the discharge measurement periods. These three installations were: 1) at the Canadian Customs Dock in Rockport, Ontario, 2) at the E.J. Noble Hospital dock in Alexandria Bay, N.Y., and 3) at the Public Dock in Clayton, N.Y. A Stevens Analog A-71 self-recording water level gauge was temporarily installed at the Canadian Customs dock in



St. Lawrence River, 1977 Hydraulic Section Locations

Figure 7-6

Rockport, Ontario, 1.3 miles below the Raft Narrows hydraulic section. This gauge provided the documentation of changes in the water surface elevation during the period of the discharge measurements. A Stevens Analog A-71 self-recording water level gauge was temporarily installed by the Detroit District, Corps of Engineers, on the downstream edge of the dock at the E.J. Noble Hospital in Alexandria, New York. This gauge was utilized to provide documentation of the water surface fluctuations during the period of measurements on the Upper Narrows Channel Section. A Stevens Analog A-71 self-recording water level gauge was temporarily installed by the Detroit District, Corps of Engineers, at the Clayton City Dock in Clayton, New York, one mile downstream of the Light No. 227 (Bartlett Point) hydraulic section. This gauge provided data on the water surface variations during the period of measurements at the Light 227 and Cedar Point Sections.

7.18.4 Discharge Computation.

The data collected during this survey were reduced using the Detroit District, Corps of Engineers, discharge measurements program. This program uses a modified form of the von Karman equation to determine the configuration of the vertical velocity curve and to compute the mean velocity of the water column in the vertical.

After the mean vertical velocity is computed, one for each panel of measurement, the area under the transverse curve is calculated by first fitting a parabolic equation through three adjacent vertical velocity points at each time. The computer then shifts over one point and fits a new curve through these three points. This process continues until the entire transverse curve is defined. The curve is integrated over the panel boundaries to provide the area under the curve. Dividing the area under the transverse curve by the panel width gives the mean panel velocity. The panel area is then adjusted for stage variations and the adjusted area is multiplied by the mean panel velocity along the appropriate directional coefficient to determine flow normal to the panel. The output from these computations is the discharge for the panel. Individual panel discharges are summed to obtain the total section discharge.

The raw data from this survey can be found in the Great Lakes Hydraulics and Hydrology Branch Archives, file GLHH 90-01, of the Detroit District, Corps of Engineers, Detroit, Michigan. Tables 7.32 to 7.36 (see Appendix C) summarize the discharge measurements taken at the five hydraulic sections.

7.19 Morrison to West Croil Islands, Massena Country Club to Central Croil Island, East Croil to West Long Sault Islands, North Wiley Dondero Canal, South Wiley Dondero Canal, Lights 45-46, Lights 43-44 and West to Central Croil Islands Sections, 1986-1987.

7.19.1 Purpose.

The Detroit District, Corps of Engineers, was requested by the Division Commander, North Central Division, Corps of Engineers, to obtain flow measurements in critical reaches of the St. Lawrence River, as related to navigation operations. These measurements were conducted, during the fall of 1986, to obtain the velocity and flow characteristics in the area of the International Rapids Section at the time record high outflows were being discharged from Lake Ontario. The measurements were collected to support the data needs of the International St. Lawrence River Board of Control of the International Joint Commission.

Hydraulic sections 4, 5, 6 and 7 (see Figure 7-7) were established to assess flow characteristics and velocity distributions in the immediate area of Copeland Cut, where critical cross-currents occur. Hydraulic sections 1, 2, 3 and 8 were established to assess the flow distribution around the Croil Islands and between the Croil Islands and the New York State mainland.

Additional discharge measurements were taken at 5 of the 8 sections in November 1987, to obtain the velocity and flow characteristics primarily in the area of the International Rapids Section at the time of low outflows (near 250 TCFS).

During the 1986 survey, the discharge measurements were taken at the following eight sections: 1) Morrison to West Croil Islands, 2) Massena Country Club to Central Croil Islands, 3) East Croil to West Long Sault Islands, 4) North Wiley Dondero Canal, 5) South Wiley Dondero Canal, 6) Lights 45-46, 7) Lights 43-44 and 8) West to Central Croil Islands. During the 1987 survey, the discharge measurements were taken only at the following five sections: Morrison to West Croil Islands, Massena Country Club to Central Croil Islands, North Wiley Dondero Canal, South Wiley Dondero Canal and Lights 45-46.

7.19.2 Description of Sections.

The **Morrison to West Croil Islands Section** (Section 1 in Figure 7-7) was established across the northern river channel, nearly perpendicular to the flow, at the westernmost tip of Croil Island to a point near the middle of Morrison Island on the easterly side of the island, approximately 7,000 feet SSW of Farran Point (Farran Provincial Park), Ingleside, Ontario. In 1986, the section was divided into 9 panels. A total of 4 discharge measurements were made on October 22, 1986. In 1987 the section was divided into 10 panels. A total of 6 discharge measurements were made between November 14 and November 16, 1987.

The **Massena Country Club to Central Croil Islands Section** (Section 2 in Figure 7-7) was established across the navigation channel, nearly perpendicular to the flow, approximately 5.5 miles upstream of the Eisenhower Lock, and near Light 56. The section line ran between a temporary control point located on the grounds of the Massena Country Club, upstream of ranges for Buoy 55, across the navigation channel to a temporary control point at the southernmost tip of Central Croil Island. In 1986, the section was divided into 12 panels. A series of 13 discharge measurements were made between October 15 and October 22, 1986. In 1987, the section was divided into 13 panels. A series of 6 measurements were made between November 14 and November 18, 1987.

The **East Croil to West Long Sault Islands Section** (Section 3 in Figure 7-7) crossed the channel between West Long Sault and East Croil Islands, nearly perpendicular to the flow, approximately 4.5 miles upstream of the Eisenhower Lock and about 1,000 feet due north of Light 50 at the downstream tip of the Delaney Shoals area. The section was divided into 12 panels. A series of 4 discharge measurements were made between October 15 and October 20, 1986.

The **North Wiley Dondero Canal Section** (Section 4 in Figure 7-7) was established across the navigation channel, nearly perpendicular to the flow, approximately 5.0 miles upstream of the Eisenhower Lock. In 1986, the section was divided into 5 panels. A series of 12 discharge measurements were made between October 13 and October 20, 1986. In 1987, the section was again divided into 5 panels. A series of 6 discharge measurements were made on November 17, 1987.

The **South Wiley Dondero Canal Section** (Section 5 in Figure 7-7) was established across the old river channel, nearly perpendicular to the flow, just south of the navigation channel and an unnamed island, due west of the Massena Oil Terminal, approximately 5.0 miles upstream of the Eisenhower Lock. The section was divided into 4 panels. A series of 13 discharge measurements were made between October 13 and October 20, 1986. An additional series of 6 discharge measurements were made on November 17, 1987.

The **Lights 45-46 Section** (Section 6 in Figure 7-7) was established across the navigation channel, nearly perpendicular to the flow, approximately 3.0 miles upstream of the Eisenhower Lock. The section was divided into 5 panels. A series of 8 discharge measurements were made between October 13 and October 16, 1986, and another series of 11 measurements were made on November 17, 1987.

The **Lights 43-44 Section** (Section 7 in Figure 7-7) was established across the navigation channel, nearly perpendicular to the flow, approximately 2.0 miles upstream of the Eisenhower Lock. The section was divided into 5 panels. A series of 6 discharge measurements were made between October 16 and October 20, 1986.

The **West to Central Croil Islands Section** (Section 8 in Figure 7-7) was established across the channel between the West and Central Croil Islands, nearly perpendicular to the flow, approximately 2,000 feet southwest of Talcotts Point on West Croil Island. The section was divided into 4 panels. A series of 4 discharge measurements were made on November 15, 1986.

The approximate locations of these discharge measurement sections are shown on Figure 7-7.

7.19.3 Measurement Techniques.

All of the sections were sounded in 1986 for this survey, using a Raytheon DE-719C Survey Fathometer. After the section was sounded, the resultant bottom profile was analyzed to determine panels, based, as nearly as possible, on uniform bottom profiles.

To measure flows as simultaneously as possible, two Monark survey launches were used by the Corps. Each launch was equipped with four metering booms and U.S.G.S. Type B-56 sounding reels. Price AA current velocity meters were used with 100-pound Columbus sounding weights and electromagnetic counters to measure velocities across established sections. Marsh-McBirney Model 527 electromagnetic current direction/velocity meters provided the basic data utilized in the computation of the directional coefficients for each hydraulic section.

After each of the section lines was established, a survey launch with three members aboard collected velocity measurements at 0.2, 0.4 and 0.8 depths at each panel point, during each measurement. These velocity measurements were collected over 180 second intervals, with a total discharge measurement taking between 45 minutes to more than 2 hours, depending upon section width, number of panels and logistics.

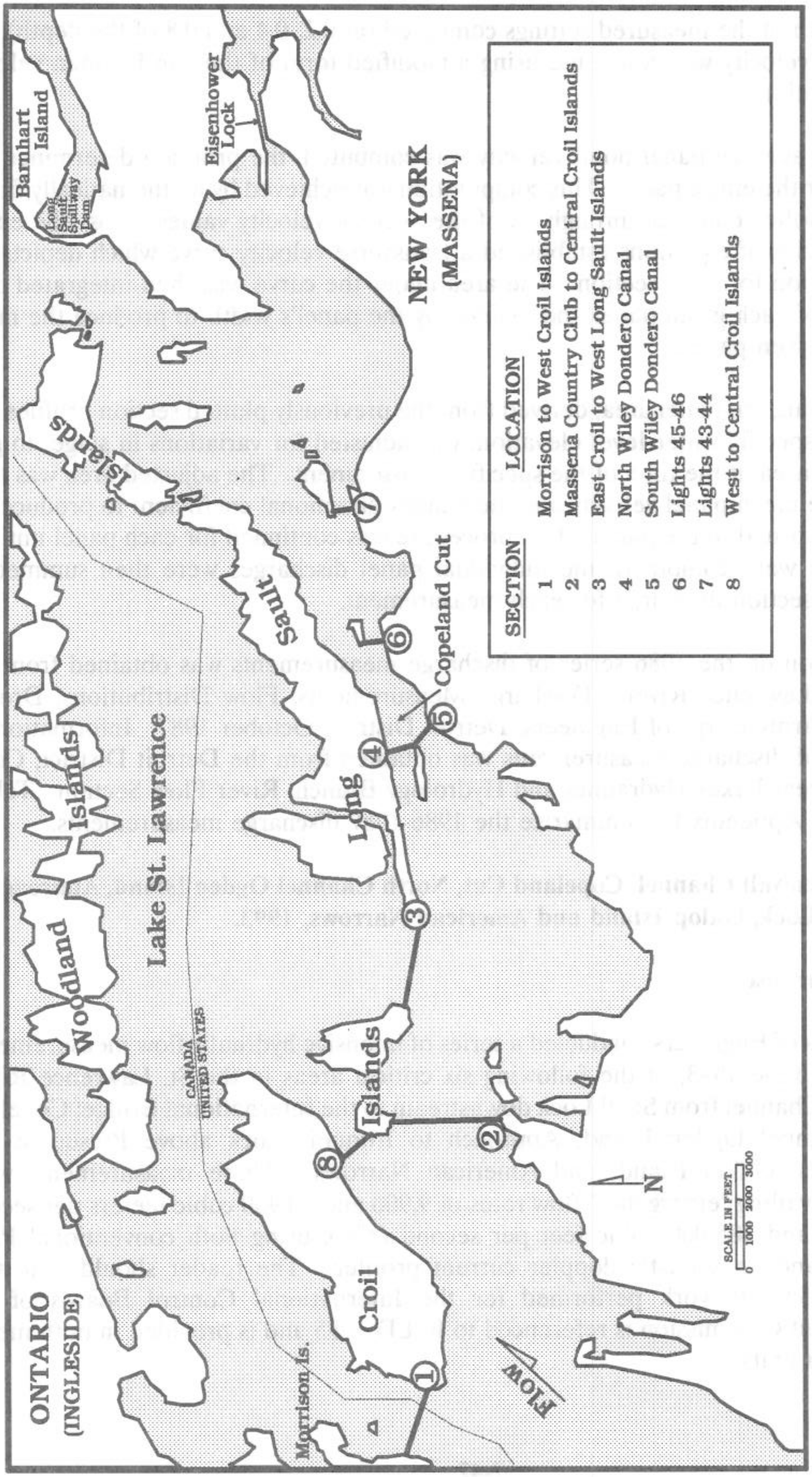
Water level information, used to reference hydraulic section geometries and to adjust cross-sectional areas during the reduction of discharge measurements, were derived from recording gauges, operated and maintained by Ontario Hydro and the New York State Power Authority. Water level data collected from the Morrisburg and Saunders Headwater gauges were principally used for these computations. The reference water surface elevations for each section were determined by a distance interpolation between the Morrisburg and the Saunders gauges; approximately 21 miles apart.

7.19.4 Discharge Computation.

The data collected during the measurements were processed using the Detroit District, Corps of Engineers, Discharge Data Reduction Program.

The areas for all the sections were determined from the soundings made in 1986.

For a given panel, the first step in the computational process was to convert the meter revolutions to velocities, using the appropriate meter rating equations. With the



St. Lawrence River, 1986 and 1987 Section Locations

Figure 7-7

velocities for each of the measured settings computed (at 0.2, 0.4 and 0.8 of the depth), the average vertical velocity was computed using a modified form of the von Karman velocity distribution equation.

After the average panel point velocity was computed, the program determined the mean velocity for the entire panel. This computation was achieved by mathematically fitting a series of parabolic equations through all of the average velocity values across the entire section. This series of equations established a transverse velocity curve which depicts the velocity distribution for each section. The area under the curve was then integrated over the boundaries of each given panel and divided by the panel's width to produce the mean velocity for the given panel.

At this point, the panel area, derived from the previously plotted section profiles and referenced to a specific water level elevation, was adjusted for variations in stage, to give the actual panel area at the time of the specific measurement. The adjusted area was then multiplied by the mean panel velocity and the panel's directional coefficient to produce the amount of flow normal to the panel. This procedure was continued for each panel until all panel discharges were computed; the individual panel discharges were then summed to obtain the total section discharge for each measurement.

Information on the 1986 series of discharge measurements was obtained from the publication "St. Lawrence River - Discharge Measurements, Flow Distributions, Drogue Surveys" - U.S. Army Corps of Engineers, Detroit District, October 1987. Information on the 1987 series of discharge measurements was obtained from the Detroit District, Corps of Engineers, Great Lakes Hydraulics and Hydrology Branch, River Flow Section. Tables 7.37 to 7.49 (see Appendix C) summarize the 1986-1987 discharge measurements.

7.20 South Cornwall Channel, Copeland Cut, North Channel Ogden Island, Approach to Iroquois Lock, Galop Island and American Narrows, 1993.

7.20.1 Purpose

The Corps of Engineers conducted a series of intensive hydraulic flow measurements, during May and June 1993, at the following six critical areas in the St. Lawrence River: South Cornwall Channel from Snell Lock downstream to the International Bridge; Copeland Cut; North Channel Ogden Island; Approach to Iroquois Lock above Presqu'ile and Toussaint Islands; Galop Island; and American Narrows. These measurements were conducted at prevailing "emergency" flow rates of 9,900 and 10,900 cubic meters per second (m^3/s) (350,000 and 385,000 cubic feet per second (cfs)), using both conventional Price current meters and an acoustic doppler current profiler. The reader should note that beginning in 1993, all work performed for the International Control Boards of the International Joint Commission is referenced to IGLD 1985 and is provided in both metric and conventional units.

These measurements were made at the request of the North Central Division of the Corps of Engineers and the International St. Lawrence River Board of Control of the International Joint Commission. The measurements were managed and conducted by the Detroit District, Corps of Engineers, with assistance from the St. Lawrence Seaway Development Corporation; St. Lawrence Seaway Authority; Environment Canada; Ontario Hydro; New York Power Authority; and the Corps of Engineers' Buffalo District, North Central Division, and Waterways Experiment Station.

The International St. Lawrence River Board of Control is responsible for recommending, on a weekly basis, outflows from Lake Ontario. One of the primary objectives of the regulation, as defined by the Orders of Approval of the International Joint Commission and referred to as Criterion (h), is to maintain the monthly average level of Lake Ontario below 75.37 meters (247.27 feet). Due to record water supplies to that lake from December 1992 to May 1993, including an all-time record supply in April 1993, the level of Lake Ontario (based on the adjusted mean) exceeded the Criterion (h) level from April 12, 1993 to July 1, 1993, with a peak level of 75.65 meters (248.20 feet) on May 5 through May 8, 1993. The Board noted that riparian damages were occurring on Lake Ontario and the St. Lawrence River, along with problems with recreational boating.

Due to the May 1993 emergency situation, the Board decided to increase the outflow above the 9,900 m^3/s (350,000 cfs) flow rate, which was underway at that time. This 9,900 m^3/s flow rate is 1,100 m^3/s (40,000 cfs) above an 8,800 m^3/s (310,000 cfs) maximum outflow specified under the regulation plan. The Board was aware that increasing Lake Ontario outflows above what had ever been experienced before would result in very high river velocities, which would pose serious safety hazards to navigation.

To determine the effect of further increasing Lake Ontario's outflows, flows were increased, on a test basis for a 24 hour period, to 10,900 m^3/s (385,000 cfs), beginning at 4:00 a.m. on Thursday, May 20, 1993. During this test period, velocity measurements were taken at several critical sections, along with observations at other sites, to closely monitor the conditions on the St. Lawrence River. Following this initial test, a series of flow increases to 10,900 m^3/s (385,000 cfs), for 24 hour periods, twice a week (Tuesdays and Fridays), were conducted from May 24, 1993 to June 11, 1993. During the days of flow increases, river navigation was restricted from Ogdensburg, New York, to St. Zotique, Québec, a distance of approximately 60 miles.

7.20.2 Description of Sections.

South Cornwall Channel: Seven transects (random measured sections, not rigidly controlled) were measured in the South Cornwall Channel, perpendicular to the navigation channel, starting at the upstream end of the training dike and extending to a point approximately 1,000 feet downstream of the Seaway International Bridge. An eighth transect was also measured, running down the middle of the navigation channel, from the downstream end of the Snell Lock guide wall to the Seaway International Bridge.

Copeland Cut: Twenty-five transects were measured in the Copeland Cut area, perpendicular to the navigation channel, starting at the upstream tips of Morrison and Croil Islands and extending to the downstream end of Long Sault Island, just upstream of the Eisenhower Lock. Two additional transects were also measured running down the middle of the navigation channel. Several of the transect measurements will be used to determine the flow split around the various islands in this reach.

North Channel Ogden Island: Thirteen transects were measured in the Ogden Island area, perpendicular to the navigation channel, starting at the Leishman Point and extending downstream just past the Murphy Islands and the city of Morrisburg. Several of the transects are intended to determine the flow split around the various islands in this reach.

Approach to Iroquois Lock: Twelve transects were measured upstream of Iroquois Lock, perpendicular to the navigation channel, starting just upstream of Sparrowhawk Point and extending downstream to Harkness Island, just upstream of Iroquois Dam. This area includes the Presqu'ile and Toussaint Island areas.

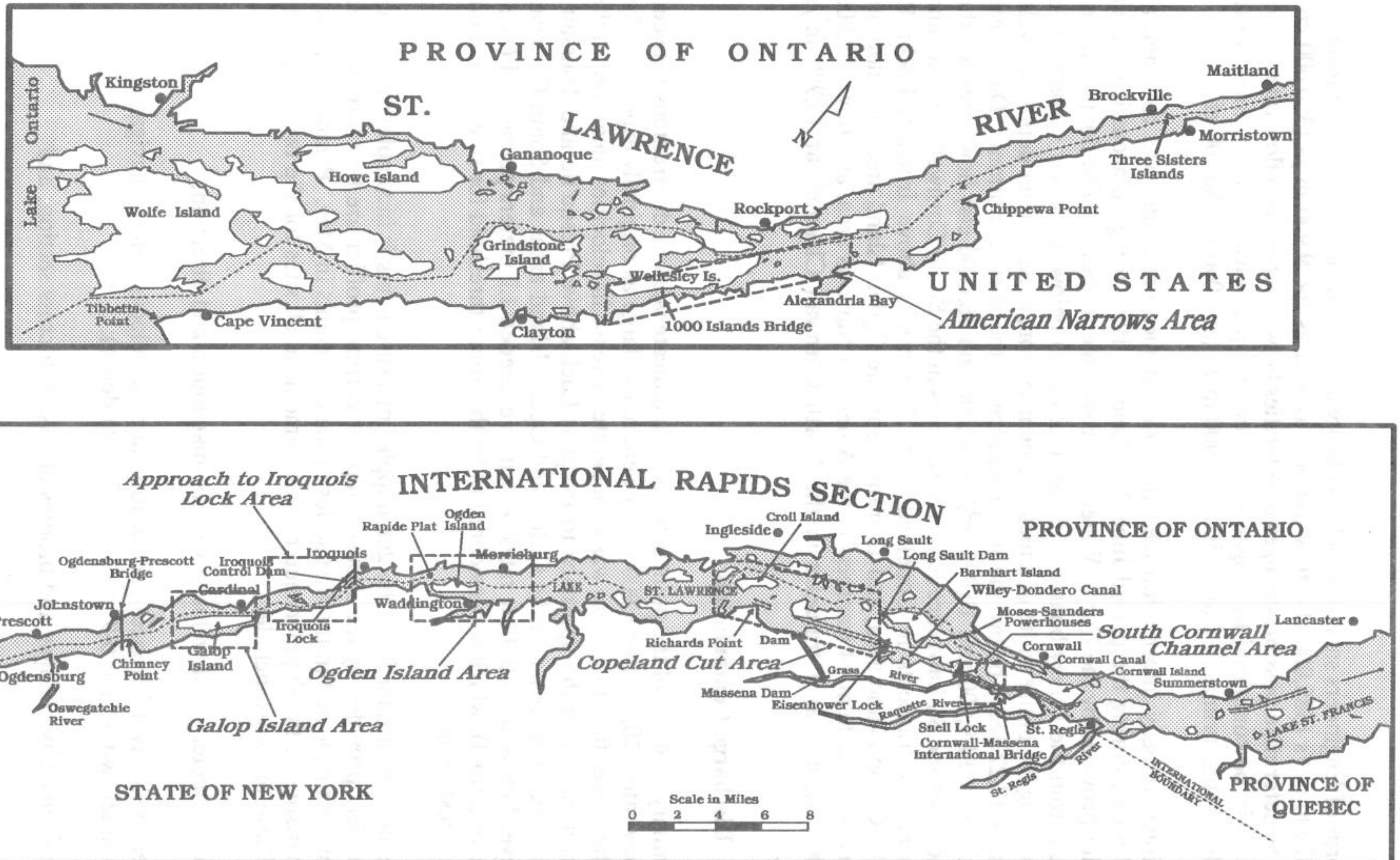
Galop Island: Eighteen transects were measured in the Galop Island area, perpendicular to the navigation channel, starting at the upstream tip of Galop Island and extending to the downstream tip of Galop Island. Several of the transects will be used to determine the flow split around the various islands in this reach.

American Narrows: Fourteen transects were measured in the American Narrows area, perpendicular to the navigation channel, starting at the upstream end of Wellesley Island and extending downstream just past the city of Alexandria Bay to the Summerland Island Group.

A report describing this measurement survey is currently being written. Much of the horizontal control during the survey was obtained from a global positioning system, which requires additional post-processing not yet completed. Nevertheless, the approximate locations of these measurement sections are shown on Figure 7-8.

7.20.3 Measurement Techniques.

The first series of measurements was conducted during the period May 20 to May 28, 1993; corresponding with the high flow test period and two of the subsequent high flow days. This measurement series concentrated on the collection of point velocities at five of the critical areas, excluding the American Narrows. The point velocities were taken from the Corps' survey launch, using conventional current meters suspended at a depth of 3.35 meters (11 feet), for between three and six locations at each of the above critical areas. The 3.35 meter depth corresponds to the standard depth for drogues used in past studies to measure velocities and current directions. The locations (horizontal control) of the measurement sections were determined through the use of a satellite global positioning system receiver provided by the St. Lawrence Seaway Development Corporation, located on



International Section of the St. Lawrence River
General 1993 High Flow Measurement Critical Areas

Figure 7-8

board the Corps of Engineers survey launch. Velocity measurements were taken during the designated 10,900 m^3/s (385,000 cfs) flow periods, as well as the 9,900 m^3/s (350,000 cfs) flow periods, to determine possible changes in velocities between these two flow rates. The measurements will be compared to drogue measurements previously taken at these areas at differing flow rates, primarily from 8,500 to 9,900 m^3/s (300,000 to 350,000 cfs).

Additional velocity information (second series of measurements) was collected at seven critical areas, during the period June 2 to June 11, 1993, using an acoustic doppler current profiler provided by the Corps' Waterways Experiment Station. The doppler meter was suspended from the survey boat at 1 meter (3.28 feet) below the water surface. It is capable of profiling the entire width of a measurement section, at half-meter depth intervals, from 2.2 meters (7.22 feet) below the water surface to the section bottom. Data were collected at designated 9,900 and 10,900 m^3/s (350,000 and 385,000 cfs) flow rates for the following reaches of the St. Lawrence River: 8 transects in the South Cornwall Channel and Pollys Gut area; 17 transects in Copeland Cut; 12 transects above Iroquois Lock; 18 transects in the Galop Island area; and 13 transects in the Ogden Island area. In addition, measurements were made at 14 transects in the American Narrows area, at a flow of 9,900 m^3/s (350,000 cfs), and at 4 transects in the North Cornwall Channel, at 10,900 m^3/s (385,000 cfs).

7.20.4 Discharge Computation.

Preliminary analyses of the point velocity data indicate velocity differentials between designated flow rates (10,900 and 9,900 m^3/s) were not as large as originally expected. For example, at the higher flow rate there was a moderate increase in velocities measured in the Copeland Cut area and in the approach to Iroquois Lock above Presqu'ile and Toussaint Islands, and a smaller increase in the Galop and Ogden Island areas and South Cornwall Channel. Nevertheless, at both flow rates velocities exceeded 1.2 meters per second (m/s) (4 feet per second (fps)), which is considered to be the upper threshold for safe navigation, in many of the test areas.

The reduction of data from the 208 doppler measurements is incomplete as of this printing. The data provided by the acoustic doppler current profiler are far more detailed than the point data collected in the first series of measurements in May. Planned analyses include comparisons of the doppler meter measurements at all sites for the two designated flow rates. These analyses include:

(1) the 3.2 meter depth velocity vectors, magnitude and direction;

(2) mean velocity differences and location of peak velocities in the navigation channel (within the 0-9 meter (0-27 foot) depth);

(3) mean velocity changes and profiles across each cross section; and

(4) the distribution and frequencies of the velocities throughout the cross section.

These analyses are intended to show the magnitude and direction of velocities in certain critical channels of the St. Lawrence River, how these velocities are affected by flow increases and to illustrate the possible effects flow increases have on navigation.

A preliminary analyses of data shows some of the information that can be obtained from the acoustic doppler current profiler measurements. For example, the four measurements taken in the South Cornwall Channel; two at 10,900 m^3/s (385,000 cfs) and two at 9,900 m^3/s (350,000 cfs), showed the highest velocities occurred north of the navigation channel, indicating a major deflection from the training dike. The full effect of these higher flows north of the navigation channel could be seen on the survey launch's track as it traversed the section. It is interesting to note that a change in flow seems to cause a greater change in vector direction than in vector magnitude. A cross section of velocities under the International Bridge looking upstream in the South Cornwall Channel, indicates that although the maximum velocity did not increase, the frequency of occurrence of velocities in the higher range has increased with the 10,900 m^3/s (385,000 cfs) flow. Additionally, the location of the higher velocities has shifted to the north side of the navigation channel. This increase in frequency of higher velocities and shift within the channel could represent a hazardous navigation environment.

A preliminary review was conducted of several of the measurements taken in Copeland Cut, at the two flow rates. By following the survey launch's tracks parallel to the navigation channel, an appreciation was gained for what ships encounter heading upbound. The survey launch was pushed to the north side of the navigation channel, as higher velocities in the deeper portion of the river course cross the navigation channel. Velocities in the cross current area, at both flow rates, were up to 60 centimeters per second (cm/s) (2 feet per second (fps)) perpendicular to the navigation channel, whereas velocities are normally less than 30 cm/s (1 fps) outside this area. A velocity cross section in the navigation channel, between the southern shore of the small island at the head of Hopsons Bay to the New York shoreline, was analyzed at both flow rates. At 9,900 m^3/s (350,000 cfs), the navigation channel bears a net 524 m^3/s (1,719.16 cfs) eastward flow, or 20 percent of the total flow between Long Sault Island and the New York mainland. At 10,900 m^3/s (385,000 cfs), the navigation channel bears a net 670 m^3/s (2,198.16 cfs) eastward flow, which is 26 percent of the total flow between Long Sault Island and the New York mainland. At 9,900 m^3/s (350,000 cfs), maximum velocities are clustered near the north side of the channel. With an increase in flow to 10,900 m^3/s (385,000 cfs), the velocities are slightly lessened, but the frequency of higher velocities is spread further across the navigation channel.

Comparing the vast amount of velocity data available from an acoustic doppler current profiler measurement versus a conventional single point velocity measurement, reveals a difference that should be noted. A single point measurement, such as gathered in May 1993, provides one velocity at a depth of 3.35 meters (11 feet), at an exact position in the river and for an exact date and time. A doppler measurement provides a snapshot of the complete velocity profile of the section, from shore to shore, and surface (-2.2 meters; -7.22 feet) to bottom, for a particular date and time. As previously stated, from initial observations, the maximum velocities, which concentrated along the north side of the navigation channel at 9,900 m^3/s (350,000 cfs), were spread over a wider band at 10,900 m^3/s (385,000 cfs). Selecting a single point value from the doppler output, at about mid-stream and for a flow of 9,900 m^3/s (350,000 cfs), gives a velocity of about 15 cm/s (0.5 fps). A similar selection from the doppler data at 10,900 m^3/s (385,000 cfs), gives a value of 40 cm/s (1.3 fps), or a difference between velocities of 160%. An integration of velocities at each flow rate would not provide a velocity differential near as great as this, which proves that single point velocity measurements in a dynamic stream such as this, are not indicative of the mechanics of the river and should be used for illustrative purposes only.

As indicated above, analysis of only one of the cross sections in each of the above noted two areas showed a nearly opposite effect between the South Cornwall Channel and Copeland Cut. It illustrates the dangers of extrapolating a few measurements across a large hydraulic system.

A final report on these measurements is expected to be completed in the spring of 1994, with figures and tables available at that time. The data and results of this survey can be obtained from the Great Lakes Hydraulics and Hydrology Branch of the Detroit District, Corps of Engineers, Detroit, Michigan. The Corps' Waterways Experiment Station has been contracted to mathematically model several of the key reaches. These efforts should be available in late 1994 or early 1995.

7.21 Summary of Discharge Measurements.

For easy reference, a matrix of the identifiable historical St. Lawrence River (International Section) discharge measurements is provided in Table 7.1. The table contains only basic information in an abbreviated format; therefore, for more information on a particular series of measurements refer to the noted subsections in the table.

TABLE 7.1 Summary of St. Lawrence River (International Section) Discharge Measurements

NAME OF SECTION	PERIOD	PURPOSE	LOCATION	MEASUREMENT TECHNIQUES	DISCHARGE MEASUREMENTS*
Ogdensburg **(See Subsection 7.1)**	Aug. 3 - Sept. 17, 1867 & June 15 - Sept. 14, 1868	To determine the flow in the St. Lawrence River	About one mile above Ogdensburg, NY	Floats	Tables 7.1 & 7.2
Ogdensburg **(See Subsection 7.2)**	1898	Not known	Near Ogdensburg, NY	Not known	Not recovered
Three Points **(See Subsection 7.3)**	Sept. 26 - Dec. 7, 1900, April 29 - July 3, 1901, Sept. 21 - Oct. 2, 1908, June 7 - Oct. 18, 1911 & Oct. 4 - 27, 1913	To determine stage-discharge equations for Lake Ontario outflow	Below Iroquois, Ont., 1500 ft. above Pinetree Point and the confluence of Parlow Creek and about 15 miles downstream from Ogdensburg, NY	Conventional	Tables 7.3 - 7.7
Three Points & **(See Subsection 7.4)**	July 12 - Sept. 27, 1914	To develop a new stage-discharge relationship for the St. Lawrence River	Below Iroquois, Ont., 1500 ft. above Pinetree Point and the confluence of Parlow Creek and about 15 miles downstream from Ogdensburg, NY	Conventional	Table 7.8
Iroquois	July 6 - Oct. 23, 1914		About 1800 ft. upstream of the Three Points Section		Table 7.9
Three Points, **(See Subsection 7.5)**	July 28 - Dec. 11, 1915, June 30 - Dec. 15, 1916, May 21 - Nov. 26, 1917, July 9 - Dec. 13, 1918, June 16 - Nov. 24, 1919 & Apr. 30 - Nov. 13, 1920	Not known	Below Iroquois, Ont., 1500 ft. above Pinetree Point and the confluence of Parlow Creek and about 15 miles downstream from Ogdensburg, NY	Conventional	Tables 7.10 - 7.15
Brockville,	Jan. 30 - May 27, 1920		Not known		Table 7.16
Iroquois Point &	Sept. 11 - Nov. 2, 1923, June 10 - Aug. 22, 1924 & Nov. 11 & 12, 1925		1800 ft. upstream of the Three Points Section		Table 7.17
Leishmans Point	Sept. 16 - Oct. 16, 1935		At Leishmans Point, NY; upstream of Ogden Island		Table 7.17

TABLE 7.1 Summary of St. Lawrence River (International Section) Discharge Measurements (cont'd)

NAME OF SECTION	PERIOD	PURPOSE	LOCATION	MEASUREMENT TECHNIQUES	DISCHARGE MEASUREMENTS*
Three Points & (See Subsection 7.6)	June 10 - Sept. 1, 1936	To check stage-discharge equations being used at the time	Below Iroquois, Ont., 1500 ft. above Pinetree Point and the confluence of Parlow Creek and about 15 miles downstream from Ogdensburg, NY	Conventional	Table 7.18
South Sault	July 29 - Aug. 5, 1936		1/2 mile below Tracy's Landing		Table 7.19
Three Points (See Subsection 7.7)	July 3 - July 20, 1945	To check the performance of the discharge rating curves being used at the time; when water levels were high	Below Iroquois, Ont., 1500 ft. above Pinetree Point and the confluence of Parlow Creek and about 15 miles downstream from Ogdensburg, NY	Conventional	Table 7.20
Three Points (See Subsection 7.8)	June 22 - July 16, 1953	To measure the river flow after demolition operations were completed at the Gut Dam Site	Below Iroquois, Ont., 1500 ft. above Pinetree Point and the confluence of Parlow Creek and about 15 miles downstream from Ogdensburg, NY	Conventional	Table 7.21 - 7.22
Three Points (See Subsection 7.9)	Dec. 21, 1953 - June 2, 1954	To determine the difference in the results obtained using Canadian and U.S. methods of making discharge measurements	Below Iroquois, Ont., 1500 ft. above Pinetree Point and the confluence of Parlow Creek and about 15 miles downstream from Ogdensburg, NY	Conventional	Table 7.23
Weaver Point (See Subsection 7.10)	Aug. 14, 1954 - Aug. 4, 1955	To determine the St. Lawrence River flow	5-1/2 miles downstream of Morrisburg, Ont.	Conventional	Table 7.24
Massena Point (See Subsection 7.11)	Oct. 10 - Nov. 4, 1960	To check the discharge computed using the Moses-Saunders powerhouse turbine ratings	1-1/2 miles downstream from the Robert H. Saunders-St. Lawrence Generating Station and the Robert Moses Power Dam	Conventional	Table 7.25

TABLE 7.1 Summary of St. Lawrence River (International Section) Discharge Measurements (cont'd)

NAME OF SECTION	PERIOD	PURPOSE	LOCATION	MEASUREMENT TECHNIQUES	DISCHARGE MEASUREMENTS*
Massena Point & (See Subsection 7.12)	May 7 - 23, 1970	To measure the distribution of flow around Cornwall Island	1-1/2 miles downstream from the Moses-Saunders Powerhouses; from Massena Point, NY, to Cornwall, Ont.	Conventional	Table 7.26
North Cornwall Channel			3700 ft. below the Massena Point Section; from Cornwall Island to Cornwall, Ont.		
Wolfe Island - North & (See Subsection 7.13)	May 4 - 15, 1972	To make flow distribution measurements around Wolfe Island, Ont.	From a peninsula on Wolfe Island, called Abraham's Head, to the Canadian mainland	Conventional	Field data available in Corps' archives File GLHH 72-5
Wolfe island - South	May 3 - 15, 1972		From Cedar Point State Park, NY, on the U.S. mainland, to south shore of Wolfe Island		
Massena Point (See Subsection 7.14)	June 10 - 19, 1972	A periodic check of the discharges obtained from the Moses-Saunders Powerhouses turbine ratings	1-1/2 miles downstream from the Moses-Saunders Powerhouses; from Massena Point, NY, to Cornwall, Ont.	Conventional	Table 7.27
Iroquois Dam (See Subsection 7.15)	July 6 - 28, 1972	To provide information with which to evaluate the terrestrial water budget and the accuracy of existing methods of determining the inflow and outflow of Lake Ontario	500 ft. upstream of the Iroquois Dam and extends from the U.S. shore north to the Canadian shore	Conventional	Table 7.28

TABLE 7.1 Summary of St. Lawrence River (International Section) Discharge Measurements (cont'd)

NAME OF SECTION	PERIOD	PURPOSE	LOCATION	MEASUREMENT TECHNIQUES	DISCHARGE MEASUREMENTS*
Cornwall Island - North Channel & (See Subsection 7.16)	Sept. 9 - 14, 1974	To determine the flow distribution around Cornwall Island; at higher flows than that measured in 1970	Between Pollys Gut and the International Bridge, across the channel from the Canadian mainland to Cornwall Isl.	Conventional	Table 7.29
Cornwall Island - South Channel			Downstream from the International Bridge, across the channel from the U.S. mainland to Cornwall Isl.		Table 7.30
Little River, (See Subsection 7.17)	Aug. 6, 1976	To obtain information on the distribution of flow around Ogden Island and discharge measurements in the vicinity of the Ogdensburg-Prescott ice boom	South side of Ogden Island; extending from the U.S. mainland to Ogden Island	Conventional	Table 7.31
Section BB93,			North side of Ogden Island; across the navigation channel to the Canadian mainland		
Ice Boom &	Aug. 14, 1976		Upstream of the confluence of the Oswegatchie River; extending from Ogdensburg, NY, to Prescott, Ontario		
Upper River	Aug. 13, 1976		1-1/2 miles upstream of Ice Boom Section, from U.S. shore about 295 ft. from the Canadian shore		

TABLE 7.1 Summary of St. Lawrence River (International Section) Discharge Measurements (cont'd)

NAME OF SECTION	PERIOD	PURPOSE	LOCATION	MEASUREMENT TECHNIQUES	DISCHARGE MEASUREMENTS*
Raft Narrows Channel, (See Subsection 7.18)	Aug. 17 - 26, 1977	To obtain data in support of the development of a St. Lawrence mathematical model	Between the northeast end of Mithchell Point, Hill Island, Ont. and the Canadian mainland	Conventional	Table 7.32
Upper Narrows Channel,			Between Towers Resort property on Wellesley Island, NY, and the U.S. mainland at St. Lawrence Park, NY		Table 7.33
Light No. 227,	Aug. 19 - 26, 1977		From Barlett Point, NY, on the U.S. mainland to Murdock Point, NY, on Grindstone Island		Table 7.34
Rift Narrows Channel &	Aug. 17 - 26, 1977		Over the channel at the Hwy. 81 bridge, between Wellesley Island, NY, and Hill Island, Ont.		Table 7.35
Cedar Point	Aug. 25, 1977		From Cedar Point State Park, NY, on the U.S. mainland, to Wolfe Island		Table 7.36

TABLE 7.1 Summary of St. Lawrence River (International Section) Discharge Measurements (cont'd)

NAME OF SECTION	PERIOD	PURPOSE	LOCATION	MEASUREMENT TECHNIQUES	DISCHARGE MEASUREMENTS*
Morrison to West Croil Islands, **(See Subsection 7.19)**	Oct. 22, 1986 & Nov. 14 - 16, 1987	To obtain the velocity and flow characteristics in the International Rapids Section at the time record high outflows were being discharged from Lake Ontario	From the westernmost tip of the Croil Islands to a point near the middle of Morrison Island; east side	Conventional	Tables 7.37 & 7.45
Massena Country Club to Central Croil Island,	Oct. 15 - 22, 1986 & Nov. 14 - 18, 1987		From the Massena Country Club grounds to the southernmost tip of Central Croil Island		Tables 7.38 & 7.46
East Croil to West Long Sault Islands,	Oct. 15 - 20, 1986		From west end of the Long Sault Islands to east end of the Croil Islands		Table 7.39
North Wiley Dondero Canal,	Oct. 13 - 20, 1986 & November 17, 1987		5 miles upstream of the Eisenhower Lock		Tables 7.40 & 7.47
South Wiley Dondero Canal,			5 miles upstream of the Eisenhower Lock		Tables 7.41 & 7.48
Lights 45 - 46,	Oct. 13 - 16, 1986 & November 17, 1986		3 miles upstream of the Eisenhower Lock		Tables 7.42 & 7.49
Lights 43 - 44 &	Oct. 16 - 20, 1986		2 miles upstream of the Eisenhower Lock		Table 7.43
West to Central Croil Islands	Nov. 15, 1986		Between West & Central Croil Islands; 2000 ft. southwest of Talcotts Point on West Croil Island		Table 7.44
South Cornwall Channel, Copeland Cut, North Channel Ogden Island, Approach to Iroquois Lock, Galop Island & American Narrows (See Subsection 7.20)	May 20 - 28, 1993 & June 2 - 11, 1993	To obtain velocity measurements in critical reaches of St. Lawrence River, during new record high outflows being discharged from Lake Ontario	South Cornwall Channel area, Copeland Cut area, Ogden Island area, Approach to Iroquois Lock area, Galop Island area & American Narrows area	Conventional point velocity measurements and Acoustic Doppler Current Profiler measurements	Analysis expected to be completed in spring of 1994

*See Appendix C (under separate cover)